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Seasonal variability and the relationship between dissolved inorganic nutrients and selected environmental parameters inshore and offshore of St. Helena Bay

by

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Declaration

I, Hassan Ebrahiem Ismail, hereby declare that I have developed and written the enclosed thesis by myself. Where collaboration with other people has taken place, or material generated by other researchers is included, the parties and/or material are indicated in the acknowledgements or references as appropriate. This work is being submitted for the Master of Technology in Chemistry at the Cape Peninsula University of Technology. It has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

	31 May 2017
Signed	**Date**

Abstract

The purpose of the present study was to apply data collected monthly over a 6-year period along the almost 200 km long St. Helena Bay Monitoring Line in the Southern Benguela upwelling system to investigate co-variation between an upwelling index calculated from nearby wind records and physical and chemical properties along the transect. The extent to which the well-documented seasonal upwelling cycles is manifested at the surface along an inshore-offshore variation was investigated in the context of implications for the validity of remote sensing as a monitoring tool in this ocean area and to improve understanding of the physical drivers of biological processes in St. Helena Bay. This study shows that surface temperature and nutrient concentrations exhibit very poor seasonality and weak correlation with the upwelling index. This is, despite clear evidence for spatial inshore-offshore gradients in temperature, nutrients, and chlorophyll-*a*, consistent with an upwelling regime. The upper ocean temperature gradient shows a much better correspondence to the upwelling index but at the same time demonstrates that surface heating, and not vertical mixing related to upwelling, controls the upper ocean temperature gradient.

In this study linear lagged correlations were also examined and discussed to gain insight into the effect upwelling has on the surface waters in St. Helena Bay with the view of determining the following: (1) Does upwelling lead to an increase or decrease of the water properties? (2) What is the characteristic lag between an upwelling event and its effect on these water properties? (3) Is the effect and/or lag different for the different seasons? and (4) Is the effect and/or lag different for stations inside the bay and those outside the bay?. A combination of surface turbulent cooling through upwelling occurred after a lag of 8 to 10 days in winter and early summer, but less than half in late summer, similar to results obtained with salinity. However, the rest of the salinity results fit in poorly with the temperature results. The only significant correlation obtained with the inshore stations during late summer is the inexplicable positive correlation at a lag of 7 days. For all three seasons virtually none of the oxygen results fit the expected pattern. All three nutrients showed a more positive correlation coefficient and significance than the negative ones. Significant negative correlations occurred mainly during late summer at lags of 7 to 9 days caused by planktonic depletion of nutrients. Also, in this season, significant positive correlations between south-north wind and nutrients only occurred at short lags. This observation supports the earlier temperature-based conclusion that the influence of upwelling develops most rapidly at this time of the year. A rapid increase in chlorophyll-*a* levels followed by nutrient enrichment of the surface layers are evident.

The results suggest that remote sensing techniques would be inadequate tools to monitor upwelling events in the Southern Benguela. Secondly, the incidence of phytoplankton blooms is more likely triggered by stratified conditions associated with surface heating than relaxation of upwelling winds. Finally, these results also emphasise the importance of validating lagged outputs against real-time measurements in supporting a simpler hydrological model in narrowing down these significant uncertainties.

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Dedications

In memory of my late father

Ebrahim Hoosain Ismail (Upadhey)

(1934 – 2017)

An esteemed and selfless individual whose unforgettable kindness and compassion

will echo in our hearts and minds forever

Table of Contents

List of Figures

List of Tables

Abbreviations and Symbols

Chl-*a* = Chlorophyll-*a*
SHB = St. Helena Bay
SHBML = St. Helena Bay Monitoring Line
DO = Dissolved Oxygen
BUS = Benguela Upwelling System
EBUS = Eastern Boundary Upwelling System
BCLME = Benguela Current Large Marine Ecosystem
AAO = Antarctic Oscillation
WAB = Western Agulhas Bank
SST = Sea Surface Temperature
HABs = Harmful Algal Blooms
SACW = South Atlantic Central Water
SICW = South Indian Central Water
AAIW = Antarctic Intermediate Water
NADW = North Atlantic Deep Water
AABW = Antarctic Bottom Water
CUS = Coastal Upwelling Systems
ENSO = El Niño-Southern Oscillation
PDO = Pacific Decadal Oscillation
NAO = North Atlantic Oscillation
DWAF = Department of Water Affairs and Forestry
DNA = Deoxyribonucleic Acid
ATP = Adenosine Triphosphate
ADP = Adenosine Diphosphate
CTDS = Conductivity-Temperature-Depth-Salinity
NOAA = National Oceanic and Atmospheric Administration
AVHRR = Advanced Very High Resolution Radiometer
EC = Electrical Conductivity
OMZ = Oxygen Minimum Zone
H_2S = Hydrogen Sulphide
MERIS = Medium Resolution Imaging Spectrometer
GEOHAB = Global Ecology and Oceanography of Harmful Algal Blooms
NCEP = National Center for Environmental Prediction
NCAR = National Center for Atmospheric Research
SBE = Sea-Bird Electronics
PSUs = Practical Salinity Units

CFA = Continuous Flow Analysis
OTCR = Open Tubular Cadmium Reactor
ASW = Artificial Seawater
UI = Upwelling Index
N = Nitrogen
N_2 = Gaseous Nitrogen
NO_2^- = Nitrite
NO_3^- = Nitrate
NH_3 = Ammonia
P = Phosphorus
PO_4^{3-} = Phosphate
Si = Silicate
KNO_3 = Potassium Nitrate
$CHCl_3$ = Chloroform
KH_2PO_4 = Potassium Dihydrogen Phosphate
Na_2SiF_6 = Sodium Hexafluorosilicate

Chapter 1

Overview

1.1 Introduction

The chemistry of the South-East Atlantic Ocean and adjacent areas prior to 1925 was not well understood, and it was not until data collected by the German *Meteor* Expedition of 1925 to 1927 were analyzed and interpreted that a picture of the large-scale distribution of elements of importance such as oxygen, phosphorous and silica began to emerge. Although the role of upwelling in the supply of nutrients (the dissolved fertilizers in the sea) in the Benguela region was appreciated as early as the 1930s, it was not until the publication of the definitive work of Hart and Currie (1960) that the nutrient chemistry was placed in a proper physical and biological perspective. Subsequent investigations by *inter alia* authors such as De Dekker (1970), Calvert and Price (1971) and Andrews and Hutchings (1980) resulted in a greatly improved understanding of the chemical and biological processes of importance in the Benguela. Chapman and Shannon (1985) reviewed the available information on the Benguela chemistry and related processes.

Changes in primary productivity have been linked to the nutrient status of marine ecosystems for over a century. Brandt (1899, 1902) first proposed that phytoplankton production must be dependent upon the supplies of nitrate-N and phosphate-P. However, quantitative tests of Brandt's hypothesis could not be performed until suitable analytical tools for the measurement of primary productivity and for the measurement of water column concentrations of inorganic nutrients, could be developed. Published data (Ketchum *et al*., 1958) from shipboard nutrient enrichment bioassays unequivocally revealed nutrient limitation of phytoplankton productivity. A decade later, (Ketchum, 1970) confirmed the existence of very strong links between nutrient availability and phytoplankton production by demonstrating a tight relationship between the concentrations of phosphorus and phytoplankton biomass measured as Chlorophyll-*a* (Chl-*a*) in seawater samples taken along a broad eutrophication gradient from oligotrophic coastal and open ocean sites. St. Helena Bay (SHB, **Figure 1**) is characterized by consistently high phytoplankton biomass, owing to persistent stratification and retentive circulation patterns, which also make it prone to red tide, particularly toward the end of the upwelling season (Pitcher and Nelson, 2006). More research is needed to establish linkages between nutrients (nitrate, phosphate and silicate) and environmental parameters (temperature, salinity, dissolved oxygen (DO) and Chl-*a*) including accurate data efforts for short-term time series, as well as further projects to help apply the knowledge gained to our understanding of nutrient dynamics and environmental parameters.

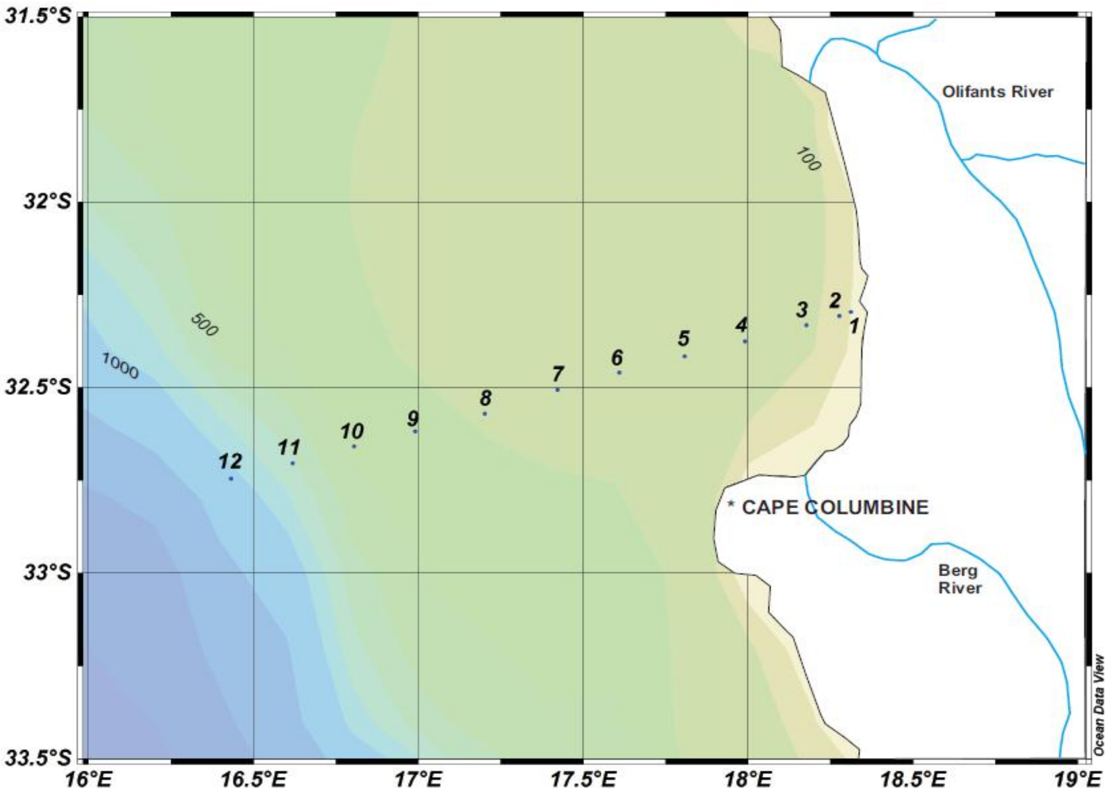


Figure 1 The SHBML station positions superimposed on bathymetry. Shallow depths are shown in green and deeper depths in blue tones.

The Benguela Upwelling System (BUS) is characterized by upwelling circulation along the entire west coast of southern Africa, and is bound at both the equatorward and poleward ends by warm water regimes, notably the Angola-Benguela front in the north and the Agulhas retroflection area in the south (Shannon and Nelson, 1996). Eastern boundary currents like the Benguela are driven by equatorward alongshore winds, which also force offshore Ekman transport in the surface boundary layer. Along the coast, this divergence results in the upwelling of cold, nutrient-rich water into the euphotic zone. A wind-driven equatorward frontal jet typically forms a boundary between the open ocean and the upwelled water, with mass balance being provided by a poleward undercurrent at depth. The enrichment of surface water inshore of the front supports high productivity and often a high frequency of harmful algal blooms. A global increase in the incidence of such blooms (Kudela *et al*., 2005) and the role of productive upwelling areas as global carbon sinks have renewed interest in understanding upwelling processes and the possible role of global change as a driving factor behind change in upwelling dynamics. Of particular interest is the application of satellite oceanography to detect upwelling events, in order to improve spatial and temporal data coverage.

According to Boyd (1987) upwelling is a dominant feature between Cape Frio (18°S) and Cape Point (34°S) in the whole Benguela system extending along much of the south coast as far as

25°E (Schumann *et al*., 1982). Shannon and Nelson (1996) gave a very clear overview of the principal characteristics of the Benguela system. Ekman transport has often been used as an upwelling index (UI) in this region (Johnson and Nelson, 1999). Although the eastern boundary upwelling system (EBUS) contribute about 11% of the global oceanic new primary production (Carr, 2002; Carr and Kearns, 2003; Monteiro, 2010) and 20% of the global catches (Freon *et al*., 2009), it represents less than 1% of the global areas of the oceans. SHB can be identified as one of the most productive regions of the Benguela current large marine Ecosystem (BCLME), in terms of wind, temperature and phytoplankton production (Hutchings *et al*., 2009b). The BCLME is one of the four major EBUS of the world oceans (Hill *et al.*, 1998), displaying substantial seasonal, interannual and decadal variability (Shannon, 1985; Shannon and Nelson, 1996). The southern BUS is of considerable biogeochemical interest due to intense primary production and high phytoplankton biomass (Compton *et al*., 2009). South-easterly trade winds in summer and predominantly westerly winds in winter influence SHB, while the Antarctic Oscillation (AAO) also influences the strength of the winter westerly winds and sea surface temperatures (SST) in the southern Benguela region (Rouault *et al*., 2010).

Cape Agulhas is considered the appropriate southern boundary as upwelling typically extends that far during summer and for this reason the Western Agulhas Bank (WAB) is considered an integral part of the productive west coast. The WAB has a highly stratified vertical water column in summer and a well-mixed water column in winter. In the middle of the WAB, a seasonal cyclonic cool SST ''ridge'' is quite evident, which is reflected in the near-surface waters (Boyd and Shillington, 1994). The Agulhas Bank is a wide and shallow feature forming the southernmost margin of the African continent (Shannon and Nelson, 1996). The continental shelf is highly variable in width in this southern region, with a minimum of 40 km off the Cape Peninsula and a maximum of 180 km located off the Orange River (Shannon, 1985). Over the continental shelf, the spectra of currents show significant peaks of periods ranging from 2.5 to 4 days (Nelson, 1989) which relates to either modulations in atmospheric forcing (Jury *et al*., 1986) or coastal trapped waves traveling poleward, with periods of 3 to 8 days, from Walvis Bay in Namibia (20°S) to Port Elizabeth (25.6°E) on the east coast of South Africa (Brundrit *et al.*, 1987; Schumann and Brink, 1990). This region is extremely important for pelagic fish spawning from September to March (Hutchings *et al*., 2002). The eggs and larvae after spawning drift northwards past Cape Town, until juvenile fish recruitment occurs north of SHB. The adult fish then make their way back to the Agulhas Bank to start spawning again in the austral spring-summer. Nevertheless, there are some important biogeographic differences between the west coast and WAB which are reflected in the composition of HABs (Pitcher and Calder, 2000).

Upwelling systems, as with many other marine environments, are increasingly susceptible to the proliferation of negative effects of harmful algae (Kudela *et al*., 2005).

The coastal jet flowing along the Cape Peninsula is another major oceanographic feature of the southern Benguela region. It shows strong, semi-permanent, surface equatorward velocities ranging from 25 to 75 cm/s (Bang and Andrews, 1974; Gordon *et al.*, 1995). Moreover, this jet acts as a major conveyor belt between the distant fish spawning areas on the Agulhas Bank and the nursery area located within this upwelling region. At the north of Cape Columbine, variability in the intensity and direction of this flow is thought to be a major contributor in the success of fish recruitment. SHB, located at the southern end of the BUS, is the best studied and one of the most productive areas in this system (Hutchings *et al*., 2012).

In **Figure 2** (Shannon and Nelson, 1996), various water masses off South West Africa such as surface ocean waters, South Atlantic Central Water (SACW), South Indian Central Water (SICW), Antarctic Intermediate Water (AAIW), North Atlantic Deep Water (NADW) and Antarctic Bottom Water (AABW) are presented. Andrews and Hutchings (1980) identified four water types in the Cape Peninsula upwelling cell: (1) Oceanic water, outside the front with T > 18°C and S = 35.4 PSU; (2) Upwelling water with 8°C < T < 10°C and S = 34.7 PSU; (3) Mixed water, found between the coast and the frontal zone with variable properties and (4) Shelf water, underlying upwelled water with T < 8°C. An upper limit of 10°C for upwelled water may be too low in cases of weaker upwelling events (Shannon, 1985). Upwelling plumes of cold nutrient-rich SACW are characterized by consistent temperature and salinity (ca 10°C and 34.80 PSU; Andrews and Hutchings, 1980; Barlow, 1982; Waldron, 1985; Brundrit, 1986). Offshore transport in a north-westerly direction, eventually causes mixing with or sinking below the warm, high salinity oceanic water (ca 20°C and 35.5 PSU**)** at a convergence front (Hutchings *et al*., 1985; Armstrong *et al*., 1987). In the summer (December to February), the sub-thermocline waters in the southern Benguela are ventilated by the ocean-shelf exchange of aerated SACW at Cape Columbine and Cape Peninsula at the southern boundary (Dingle and Nelson, 1993). In the winter (June to August), there is a disruption of the thermocline and a complete re-aeration of the water column.

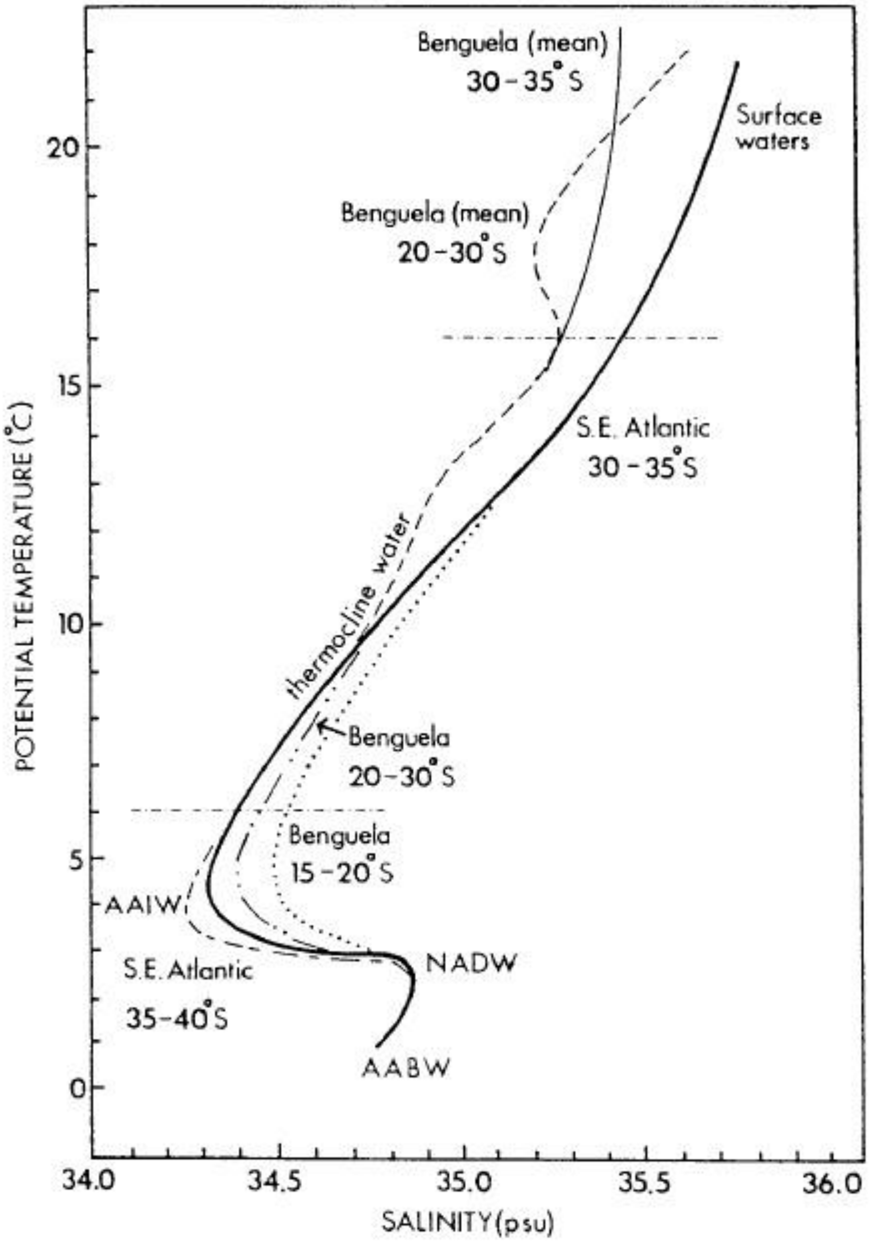


Figure 2 The principal water masses of the south-east Atlantic and Benguela system. The potential temperature-salinity (T-S) characteristics of water mixing in the water column. Adapted from Shannon and Nelson (1996).

The southern Benguela unlike its northern counterpart, is a seasonal upwelling system modulated by intra-seasonal variation between mid-latitude cyclones moving westward and a ridging South Atlantic anticyclone (Shillington *et al.*, 2006). In the SHB region the biogeochemistry was found to be well expressed seasonally, when decreased ventilation due to strong stratification at the end of summer resulted in hypoxia which is conducive to anaerobic remineralization in sediments. Water column stratification seasonally from summer heat flux plays an important role in the southern Benguela with regards to biogeochemical variability

(Monteiro *et al*., 2006). St. Helena Bay (SHB) is also a part of the BUS that is characterized by expansive red tides and with significant variability spatially and temporarily. Red tides typically develop in response to upwelling relaxation and are characterized by a phytoplankton community shift from diatoms to dinoflagellates. Currents are among the most important physical features of upwelling systems (Fraga *et al.,* 1988; Pitcher *et al*., 1998; Trainer *et al*., 2002). Changes in upwelling intensity provide one of the substantiated lines of evidence for nutrient and environmental trends, although the specific responses are still being established. There is a need to compare seasonal variability of nutrients among upwelling systems. The study in this region will allow comparisons to be made on the effects of the seasonal timing of environmental parameters on nutrients.

Coastal upwelling systems (CUS) are largely determined by the continental shelf and upper slope bathymetry, and by coastline morphology. In coastal upwelling regions, usually Ekman transport drags the surface waters outwards with a deep current moving towards the coast. In the Benguela system, shoreward flow on the leeward side of upwelling plumes seem to be areas where harmful algal blooms (HABs) species, such as *Gymnodinium catenatum* and *Alexandrium catenella* can develop and accumulate in close proximity to upwelling centres without being advected away (Moita *et al*., 2003). Variations in the wind regime due to changes in the position and/or strength of the high-low pressure systems cause short-term variability in upwelling-downwelling cycles within each season (Hickey, 1998; Shillington, 1998). Interannual fluctuations related to the El Niño-Southern Oscillation (ENSO) and longer-term cycles, such as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO), also affect these coastal upwelling systems through modifications of seasonal upwelling-downwelling strength (Shannon *et al*., 1986; Blanton *et al*., 1987; Simpson, 1992; Alvarez-Salgado *et al*., 2003).

1.2 Objectives

In order for the objectives to be accomplished, dissolved inorganic nutrient and selected environmental parameter data were collected monthly inshore and offshore of SHB, off the west coast of South Africa from January 2004 to December 2009.

Four specific objectives were set for this study:

Objective 1: To investigate the relationship between dissolved inorganic nutrients and environmental parameters inshore and offshore of St. Helena Bay over seasonal cycles from January 2004 to December 2009.

Objective 2: To investigate coastal upwelling processes of dissolved inorganic nutrients onto the continental shelf.

Objective 3: To investigate the validity of remote sensing as a monitoring tool in this ocean area and to improve understanding of the physical drivers of biological processes in St. Helena Bay.

Objective 4: To investigate a characteristic lag between an upwelling event and its effect over seasonal cycles in this study area.

1.3 Research Design and Methodology

The purpose of the present study is to apply data collected monthly over a 6-year period along the almost 200 km long St. Helena Bay Monitoring Line (SHBML) in order to investigate co-variation between an upwelling index calculated from nearby wind records and physical and chemical properties along the transect. The extent to which the well-documented seasonal upwelling cycles is manifested at the surface along an inshore-offshore area was investigated in the context of implications for the validity of remote sensing (Santos *et al*., 2012) as a monitoring tool in this ocean area and to improve understanding of the physical drivers of biological processes in SHB. In this study linear lagged correlations will also be carried out, examined and discussed using surface data collected on the SHBML to gain insight into the effect upwelling has on the surface waters in SHB with the view of determining the following: (1) Does upwelling lead to an increase or decrease of the water properties (temperature, salinity, etc.)? (2) What is the characteristic lag between an upwelling event and its effect on these water properties? (3) Is the effect and/or lag different for the different seasons? and (4) Is the effect and/or lag different for stations inside the bay and those outside the bay?.

1.4 Thesis Outline

The layout of this dissertation is structured as follows:

Chapter 1 provides a background and introduction to the research topic, including an overview of the effect of upwelling in this study area. The introduction also serves to introduce the southern Benguela and also review previous nutrient dynamics studies which have been undertaken in the area. **Chapter 2** provides a literature review which relates to a description of St. Helena Bay as well as the environmental variables for the study. **Chapter 3** provides a detailed account of the materials and methods used in this study. In **Chapter 4**, the results are presented and discussed. A summary of conclusions is presented in **Chapter 5**, as well as recommendations for further studies on nutrient dynamics and selected environmental parameters inshore and offshore of St. Helena Bay, off the west coast of South Africa in relation to the primary aim and objectives of the research study. A published paper relevant to this research project, plus posters presented at National/International scientific conferences and based on the results of this research, are listed in Appendix 2.

Chapter 2

Literature Review

2.1 General Description of St. Helena Bay

St. Helena Bay (SHB) is a highly productive (Mitchell-Innes and Walker 1991) open bay lying adjacent to the Cape Columbine upwelling center, one of the major upwelling sites and retention zone for nutrient rich water (Monteiro and Roychoudhury, 2005) on the west coast of South Africa (**Figure 1**). The west coast is one of the richest fishing grounds in the world and attracts large colonies of sea birds and seals (Branch, 1981). Newly upwelled water is advected around the Cape Columbine headland into the Bay, resulting in surface currents in the bay to be sluggish, forming an anticyclonic eddy in the lower bay that abuts a much larger cyclonic gyral system to the north (Holden, 1985). In addition, close to the coast, the subsurface flow is often polewards (Shannon, 1985). During episodic upwelling events, which occur at 5 to 10 day intervals throughout the summer months in response to changes in wind stress, cold bottom water advects onto the shelf, forming a large-scale surface tongue that extends northward (Nelson and Hutchings,1983). The hydrography within the bay can be complex (on a short-term scale), and strongly modulated by the event scale (Shannon, 1985). The circulation patterns within the bay prolong residence time up to 25 days (Bailey and Chapman, 1991). Shannon (1985) has indicated that south of 32°S the coastline is irregular with several capes (formed by granite outcrops, *e.g.* Cape Columbine 32°S, Cape Peninsula 34°S and Cape Agulhas 35°S) and bays (*e.g.* St. Helena Bay, Saldanha Bay, Table Bay and False Bay).

Dissolved inorganic nutrients are primarily brought in either as atmospheric input or carried by the Berg River. The Berg River and its tributaries primarily flow through areas dominated by agriculture, wineries, canneries and textile milling (Fourie and Steer, 1971). However, it is also subject to incidence of HABs and regular episodes of oxygen depletion in the coastal waters, which in the past have led to major mortality events for organisms such as rock lobsters and fish (Cockroft *et al*., 2000, Monteiro & Roychoudhury, 2005) and has been an important part of the West Coast lobster fishing grounds (Hutchings *et. al*., 2012). In addition, a rock lobster reserve has been declared within SHB in terms of the Marine Living Resources Act. Tourism is also becoming an increasingly important industry supported by SHB, given its picturesque and sheltered nature and the variety of recreational opportunities it offers including sailing, canoeing, surfing, bathing, diving, kite surfing and beach activities.

2.2 Nutrients

A major source of nutrients to the marine environment includes the adjoining ocean (through upwelling), the atmosphere (in the form of precipitation), local water-column production and sea bed recycling of biologically produced organic compounds (Tett *et al*., 2003). Much of the regeneration of nutrients takes place in the marine sediments, the site of substantial biological and chemical activity (Valiela, 1980; Allanson and Baird, 1999). Sinking particles do not remain exposed to microbial and animal consumers for long in the water and fall to the bottom (Valiela, 1980). Although, transformation in sediments are mediated principally by bacteria, the resulting gradient of nutrients is released to the overlying water column (regeneration) where they may be taken up by plants in primary production, or adsorption (burial) into deeper sediments (Herbert, 1999). These two processes, along with phytoplankton uptake, are the most significant sink for dissolved inorganic nutrients (Tett *et al*., 2003).

The availability of nitrogen (a key constituent of all living matter) is essential for primary production in plants and is generally considered to be one of the major factors limiting eutrophication (Herbert, 1999). Nitrogen can occur in a variety of oxidation states ranging from +5 (nitrate) to -3 (ammonium), as a result the conversion of nitrogen through these various oxidation states is a biologically controlled process (Tett *et al*., 2003). Nitrogen concentration is determined principally by inputs from fluvial discharge and from exchange across the sediment-water interface. Increased nitrogen concentrations can arise from anthropogenic inputs into oceanic water, for example, addition of agricultural fertilizers, sewage discharge and organic industrial wastes (DWAF, 1996). All living matter, irrespective of its origin contains nitrogenous macromolecules (e.g. nucleic acids, proteins and polyamino sugars) which become available upon death and sinking of cells to decomposer organisms.

Nitrate formation is an energetically expansive two-step enzymatically driven process (Tett *et al.,* 2003). Some species of phytoplankton (prokaryotes), possesses the enzyme nitrogenese (Herbert, 1999), which is capable of fixing gaseous nitrogen (N_2), dissolved in water, into ammonia and hence into organic nitrogen. This process, called nitrogen fixation, is energy demanding due to the strength of the dinitrogen (N-N) bond, regulated by carbon availability and other physico-chemical factors. There is a tendency for richer waters to support higher rates of this process (Valiela, 1980).

Whilst nitrogen fixation fixes nitrogen from an external source, the release of ammonium from nitrogenous matter is known as **ammonification**, and depending on the structural complexity of the organic matter, this can be either a simple deamination reaction or a complex series of metabolic steps involving a number of hydrolytic enzymes during which nitrogen-containing polymers are broken down into their mono-metric sub-units (Herbert, 1999). **Nitrification** is a microbial process where reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and nitrate. The nitrification process is primarily accomplished by two groups of autotrophic nitrifying bacteria that can build organic molecules using energy obtained from inorganic sources, in this case ammonia or nitrite.

In the first step of nitrification, ammonia-oxidizing bacteria oxidize ammonia to nitrite according to equation (1).

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^- \qquad (1)$$

In the second step of the process, nitrite-oxidizing bacteria oxidize nitrite to nitrate according to equation (2).

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^- \qquad (2)$$

Reductions in pH and alkalinity can be a symptom of nitrification, as shown by hydrogen ion formation in equations (1) and (2). Nitrite and nitrate are produced during nitrification through ammonia utilization by nitrifying bacteria. According to equations (1) and (2), for every mole of ammonia-N produced, a 1-mole equivalent of nitrite-N is produced. Subsequently, for every mole of nitrite-N produced, a 1-mole equivalent of nitrate-N is produced. Whereas nitrification involves the oxidation of reduced nitrogen, **denitrification** is a reductive process, whereby heterotrophic bacteria utilize nitrate as a terminal electron acceptor and reduce it to either gaseous products, or ammonium (nitrate ammonification). Denitrification is a key process in the sediment nitrogen cycle as it decreases the amount of nitrogen available to primary producers (Herbert, 1999), and dominates in areas where there is an oxygen deficiency, thereby substituting the oxygen through nitrate reduction and thus becoming the most efficient energy extractors (Knowles, 1982, Tyrrell and Lucas, 2002).

Phosphorus is an essential macronutrient which, with nitrate, is considered to be the principal nutrient controlling the degree of eutrophication in marine ecosystems. It is accumulated by a variety of living organisms where it forms part of DNA (ATP and ADP) molecules that store energy and fats of cell membranes (DWAF, 1996). Elevated levels of phosphorus may result from point-source discharges such as domestic and industrial effluents, particularly waste products from manufacturing phosphoric acid for fertilizer production, and non-point sources such as atmospheric precipitation, urban run-off, and drainage from agricultural land, in particular land to which fertilizers have been applied (DWAF, 1996). Phosphorus concentrations in the marine environment are controlled by a number of biotic and abiotic factors. Biological control of phosphorus concentrations takes place in the form of assimilation by bacteria and phytoplankton (under favorable light conditions) of orthophosphate taken up from the surface of organic detritus and suspended particles, which are then consumed by filter feeders and excreted as inorganic phosphorus (Sobehrad, 1997). An inorganic buffering effect maintains a relatively constant level of phosphorus concentrations due to adsorption of phosphorus from the sediments (Sobehrad, 1997). Orthophosphate ions are adsorbed by aluminium oxides (chemisorption), and precipitation of phosphate with either iron or aluminium oxides or dissolved calcium forms solid compounds in the water column, which may represent relatively long term storage of phosphorus as regeneration is very slow due to the stability of the complexes formed (DeBusk, 1999). This continuous two-step process of release and adsorption by the factors mentioned maintains equilibrium between the water column and the sediments (Winter and Baird, 1991). As with nitrogen, phosphorus is typically depleted in the euphotic zone in the marine environment, increasing in concentration with depth due to a steady down drift of organic debris and faecal pellets (containing assimilated phosphate), which subsequently require a means of transport back to the surface zone.

Silicate is a major constituent of diatoms and a bio-limiting nutrient, which use silicate to encase their cells in a wall impregnated with silica (DWAF, 1995). The processes involved in the silicon cycle (https://www.britannica.com/science/ocean/images-videos/cycling) are fewer than that of nitrogen or phosphorus, comprising essentially only river (through drainage of silicate-rich basins) and ocean inputs, removal of dissolved silicon by diatoms and then dissolution from these cell walls on the sea bed upon death and settling (a slow process, Tett *et al.*, 2003). The importance of the quality of water delivered to the marine environment thus cannot be overlooked. An illustration of the silicon cycle is represented in **Figure 3** below.

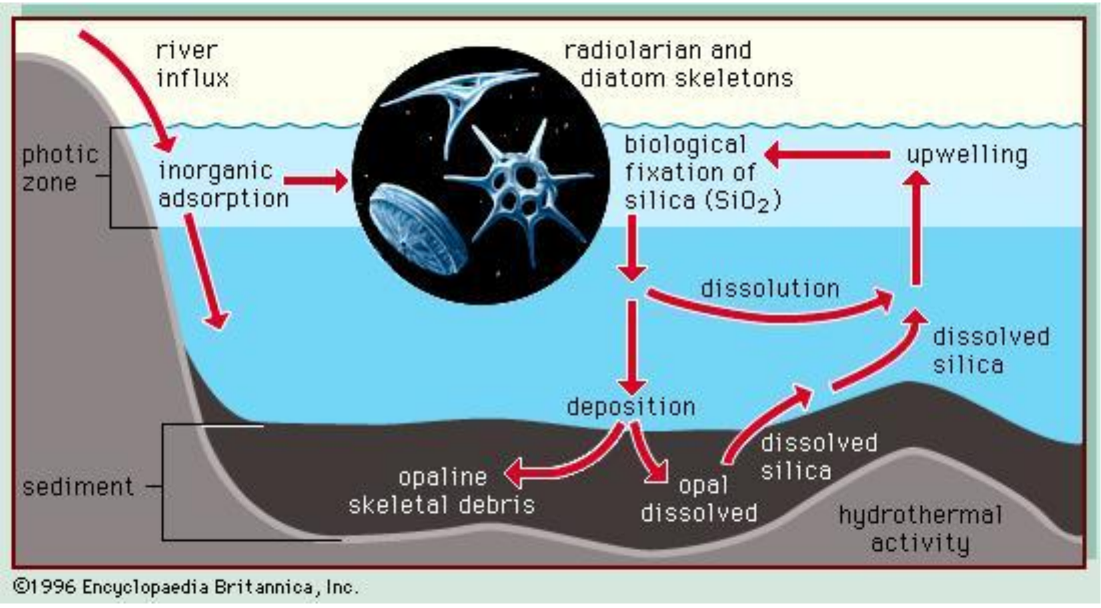


Figure 3 The silicon cycle. 1996 Encyclopaedia Britannica, Inc.

2.3 Temperature

Generally, the natural temperature regime on the west coast is largely influenced by wind-induced upwelling (south-easterly and southerly winds) which varies seasonally. Seasonality is strongest in the south where south-easterly winds are rare in winter but common in summer (DWAF, 1996). Although velocities are lower in winter, seasonality diminishes to the north-west where the wind generally comes from the south throughout the year (Shannon, 1985; Nelson and Hutchings, 1983). Depending upon the ‘strength’ of the upwelling process, temperatures of the upwelled waters range from 9 to 14°C (Shannon, 1985). These temperatures can increase to 16°C and higher through sun warming after being upwelled (Brown, 1992). The mixed water is bound by an oceanic front which lies at or slightly offshore of the shelf break (Andrew and Hutchings, 1980). Temperatures of oceanic water in the area are about 20°C (Shannon, 1985). Anthropogenic sources which may influence water temperature in the marine environment are usually related to the discharge of cooling water from power stations and certain industries (World Health Organization, 1982). Typical water quality problems which may be associated with temperature include: eutrophication, general growth deficiencies, lowered reproduction, changes in feeding habits and changes in respiration patterns (DWAF, 1996). Temperature is measured *in situ*, using a Conductivity-Temperature-Depth-Salinity (CTDS) meter. The average zonal surface temperature for the oceans and land (**Figure 4**) as well as the average February sea surface temperature (SST) for this study period (**Figure 5**) is illustrated below.

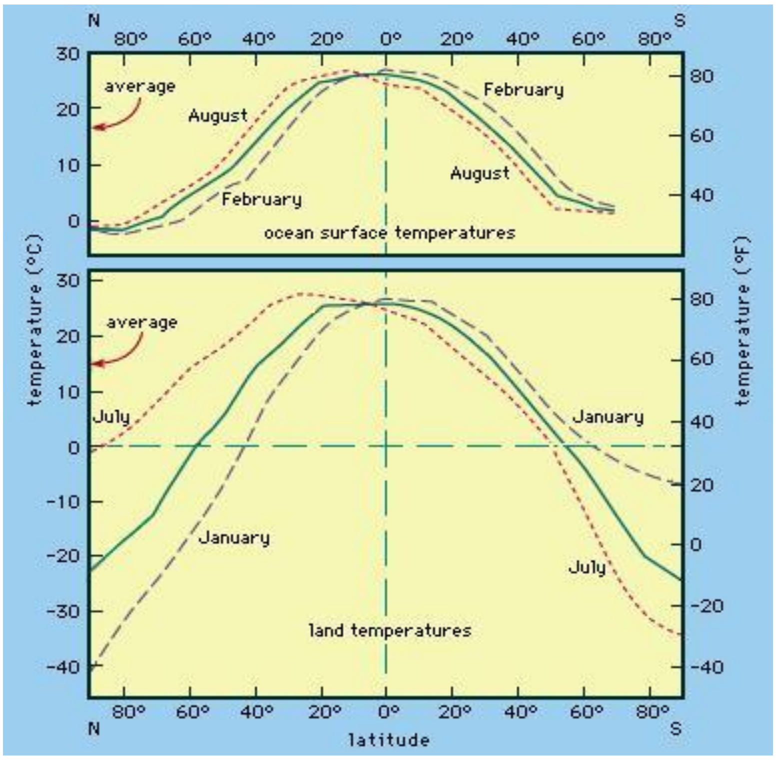


Figure 4 Average zonal surface temperature of the open oceans and land, with annual temperature ranges for both. 1996 Encyclopaedia Britannica, Inc.

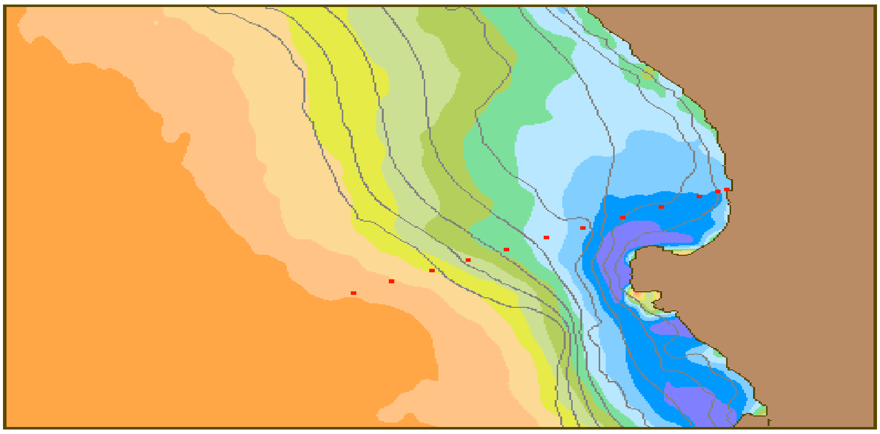


Figure 5 The SHBML station positions superimposed on the average February sea surface temperature field derived from National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite images. The coldest temperature is shown as dark blue and the warmest as orange.

2.4 Salinity

Salinity falls in the narrow range of 34,7 x 10^{-3} to 35,4 x 10^{-3} along the west coast and the lower salinity values are associated with cold upwelling water. Land run-off is low and intermittent and thus dilution of the salts only occurs in much localised areas, e.g. the Berg River mouth and the smaller estuaries further south. Due to loss by evaporation, salinity as high as 37 x 10^{-3} has been recorded in the Langebaan lagoon area. On the south coast, there is slight seasonal salinity variations with highest salinities in summer (35,4 x 10^{-3}) and lowest values in winter (35 x 10^{-3}). Generally, a slight positive salinity gradient from the shoreline in the east to the core of the Agulhas current is evident, and salinity is not interdependent on other water quality properties or on other constituents. According to *The International System of Units (SI) in Oceanography*, the unit for salinity is dimensionless, reflecting ratios between two electrical conductivities. The conductivity of a seawater sample at 15°C, 1 atmosphere pressure and the standard conductivity of standard KCl solution being 32,4356 g.kg^{-1}. Where the ionic strength (salt content) of seawater has been measured as electrical conductivity (EC), mS m^{-1}, conversion factors from EC to salinity in the range 32 x 10^{-3} to 36 x 10^{-3}, at different temperatures can be used. Anthropogenic influences on salinity in the marine environment are usually related to waste discharges (fresh water) which, depending on the volume discharged, may result in a short-term decrease in salinity in the immediate vicinity of the discharge. A map of ocean salinity is illustrated in **Figure 6.**

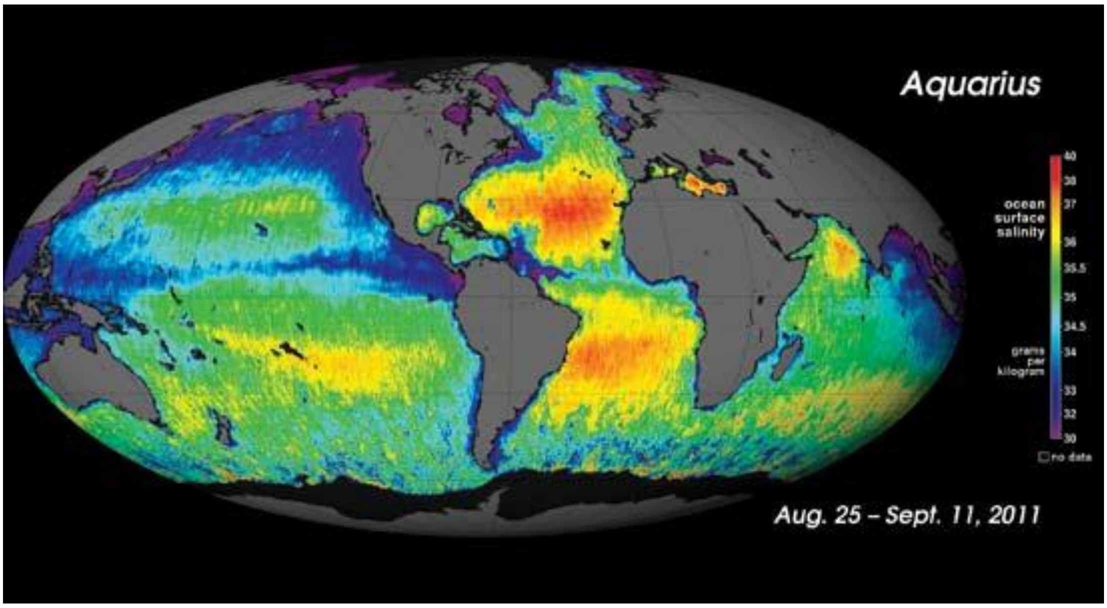


Figure 6 The first map of ocean salinity taken by the Aquarius/SAC-D spacecraft, August to September 2011. 1996 Encyclopaedia Britannica, Inc.

2.5 Dissolved Oxygen

Climate models with biogeochemical components predict declines in oceanic dissolved oxygen (DO) and a consequent expansion of the mid-depth oxygen minimum zone (OMZ) under global warming conditions (e.g. Matear *et al*., 2000; Bopp *et al*., 2002; Oschlies *et al*., 2008). In particular, models driven by increasing greenhouse gases predict a decline in mid-depth oceanic DO as a result of enhanced stratification and reduced ventilation (Sarmiento *et al*., 1998; Keeling and Garcia, 2002). In the past few years, changes in DO content have become a focal point of oceanic research, mainly due to their large impacts on ecosystems and water column chemistry. Therefore, according to Bograd *et al*., (2008), understanding the interactions among ocean oxygen changes driven by climate change, upwelling-driven hypoxia, and ecological perturbations is extremely critical. Anoxic conditions (complete depletion of oxygen) have an even greater biogeochemical impact (Stramma *et al.,* 2010). For instance, increased marine production of N_2O due to intensifying anoxia was also reported on the Indian continental shelf (Naqvi *et al*., 2000). In addition to oxygen changes over recent decades and the potential future oxygen declines suggest the need for an improved observing system to track ocean oxygen changes (Keeling *et al*., 2010).

For the inshore stations of SHB, thermocline depths in the period 2004 to 2009 generally varied between 15 and 25 m, being shallower in summer and deeper in winter (Hutchings *et al*., 2012). Fluctuations at the event scale of 3 to 6 days is evident for oxygen values in the upper mixed layer. This variable, measured once per month, are aliased by the event-scale of upwelling (5 to 15 days). Therefore, observed changes in sub-thermocline waters illustrate seasonal events of oxygen concentrations clearly (Nelson and Hutchings, 1983). Bailey (1991) very clearly demonstrated that there is a definite southward increase in the seasonal development of hypoxia in the water column on the Benguela shelf and that there is also a definite maximum in the extent and severity of hypoxia in late summer and a minimum in winter, when winter mixing and reduced surface primary production are thought to play a role in ventilating the shelf waters off Cape Columbine. Off South Africa, the short-term impact has highly negative consequences to the local fishery (Cockcroft, 2001), which results in a substantial loss of income to fishing companies and local communities. The long-term impact of low oxygen water events on local rock lobster populations felt along the South African west coast from the Orange River to approximately SHB depends on the severity of the event in the area affected, and whether or not hydrogen sulphide (H_2S) was produced (Cockcroft, 2001).

2.6 Chlorophyll-*a*

Harmful algal blooms (HABs) feature regularly on the west coast of South Africa, particularly during the latter part of the upwelling season (Pitcher *et al*., 1998; Pitcher and Calder, 2000), when the contribution of dinoflagellates is greatest to the phytoplankton community (Fawcett *et al*., 2007). The present study focuses on the SHB region, where a broadening of the shelf downstream of the Cape Columbine cell at 33°S (**Figure. 1**) is evident. Previous observations in this region have shown phytoplankton life-forms with levels of mixing and stratification at varying temporal and spatial scales, and a seasonal increase in dinoflagellates towards autumn as stratification increases, as previously identified by remotely sensed chlorophyll data (Pitcher and Weeks, 2006). High concentrations of Chl-*a* have been observed throughout the year in SHB (Shannon *et al*., 1984). However, Bailey (1985) assumed to reflect enhanced primary productivity in this area, and SHB in itself has shown to be an area of comparative homogeneity, where standing crops of phytoplankton and zooplankton are higher and more consistent than in the plume area off the Cape Peninsula (Hutchings, 1981). The high productivity in this area of study is a result of: (1) the (periodic) resupply of nutrients to the euphotic zone through upwelling; (2) the (relative) stability of the physical environment; and (3) the (retentive) circulation in the region (Pitcher *et al*., 1992).

Chl-*a* satellite images from two study periods (2005 and 2006), derived from medium resolution imaging spectrometer (MERIS) data using an experimental algorithm (Bernard *et al*., 2005), illustrates the differing spatial nature of bloom events in response to physical forcing. In the 2005 study, characterisation of an inshore appearance of a narrow band of high phytoplankton biomass is dominated by dinoflagellates, in association with a nearshore poleward flow during wind relaxation and stratified conditions (**Figure 7a**). This is consistent with observations and conceptual modelling of Pitcher and Nelson (2006). The 2006 study resulted in persistent upwelling-favourable winds leading to equatorward near-surface currents and a much cooler mixing water column; *Pseudo-nitzschia* spp. co-dominated a spatially extensive diatom bloom (**Figure 7b**).

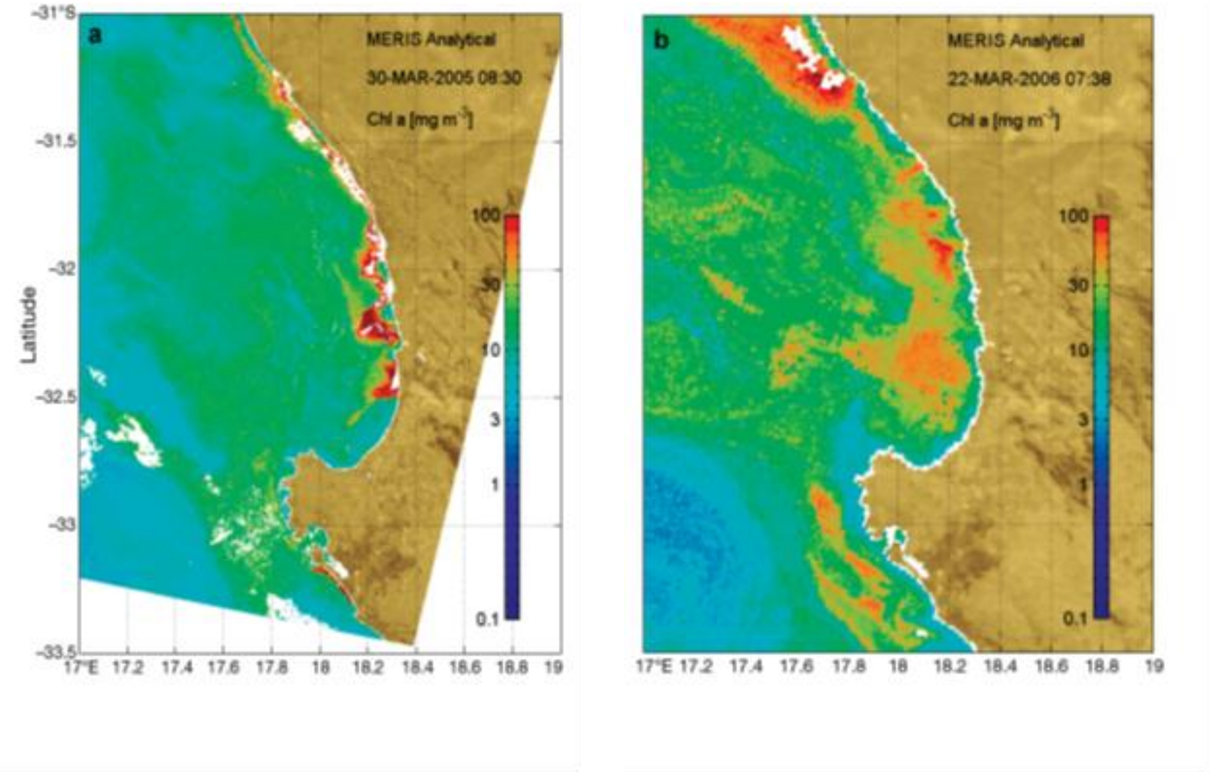


Figure 7 Medium Resolution Imaging Spectrometer (MERIS) Chl-*a* images of St. Helena Bay region for: (a) 30 March, 2005 and (b) 22 March 2006. Chlorophyll-*a* levels were calculated using an experimental algorithm (after Fawcett *et al*., 2007).

2.7 Eutrophication

Both our knowledge and our ability to manage marine eutrophication have expanded tremendously during the last couple of decades; this knowledge has been summarized extensively in several synthetic reviews (Smith *et al*., 1999; Smith, 2003, 2006). Smith *et al*. (1992) published a remarkably similar volume that described the physical, biogeochemical, and ecological aspects of eutrophication in Chesapeake Bay. It can be argued that, in general, the results of nutrient over-enrichment tend to be negative, with beneficial effects being rare or accidental (Fisher *et al*., 1995). In particular, eutrophication often has a strongly negative economic dimension (Segerson and Walker, 2002): in England and Wales, for example, the damage costs of freshwater eutrophication alone have been estimated to be £75 to 114 million per year (Pretty *et al*., 2003). Similarly, the economic consequences of coastal marine eutrophication can be very substantial, and are expected to increase over time worldwide as human population numbers grow and move into coastal communities.

Organic loading is of particular concern for SHB given the number of fish processing facilities that are operational in the bay and the fact that the bay is a retention zone. High organic loading typically leads to eutrophication, which may bring about a number of community responses. These include increased growth rates by primary producers, disappearance of organisms due to hypoxia or anoxia, reduction in the number of species following repeat hypoxia, complete disappearance of benthic organisms in severely eutrophic/anoxic sediments and even changes in community composition (Warwick, 1993).

2.8 Other Coastal Upwelling Regions

The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) program espouses a comparative approach to studying HAB ecology, in which natural events are compared and contrasted within and between regions to elucidate common forcing mechanisms as well as regionally distinct influences (GEOHAB, 2005; Anderson *et al*., 2005; Kudela *et al*., 2008). There is growing evidence of bloom incubation in sheltered regions of coastal upwelling systems (CUS), including Lisbon Bay, Portugal (Moita *et al*., 2006), Paracas Bay, Peru (Kahru *et al*., 2004) and Monterey Bay (Ryan *et al*., 2009). Of these locations, perhaps the most thoroughly characterized is Monterey Bay. Common characteristics of SHB and Monterey Bay include: (1) upwelling flows separate from the coast and extend across the mouth of the bay, creating distinct zones and sharp frontal boundaries; (2) retention inshore of the upwelling plumes favour stratification and development of dinoflagellate blooms, and retention is evident during both upwelling and relaxation; (3) intensity of the dinoflagellate blooms is strongly influenced by physical concentration mechanisms. In SHB, drifter and model studies indicate that strong nearshore poleward currents develop within and adjacent to the bay during wind relaxation/reversal (unpublished results), suggesting a potential similarity to Monterey Bay, however, none of the limited SHB drifter observations were made during red tide bloom periods. Due to limited observations, definitive differences between the dinoflagellate ecology of these systems are less certain. One apparent difference is that while red tide can persist in Monterey Bay through upwelling and relaxation, red tide is primarily a relaxation-period phenomenon in SHB.

Chapter 3

Materials and Methods

3.1 Study Area

The study area is the St. Helena Bay Monitoring Line (SHBML) in the Southern Benguela, along the west coast of South Africa (**Figure 1, Table 1**). Stations 1 to 12 have bottom depths of 27 to 1396 m, respectively, and are located at distances ranging from 3 to 191 km offshore. The Berg River discharges into SHB at Veldrift and drains a catchment dominated by agriculture, wineries, canneries, and textile milling (Fourie and Steer, 1971; de Villiers, 2007). Monthly cruises on the research vessels RV *Africana*, RV *Algoa*, and RV *Ellen Khuzwayo* were conducted along the SHBML from January 2004 to December 2009. The SHBML is typically sampled only once during the two-month long October/November pelagic spawner biomass survey. In this study, a total of 62 SHBML cruise datasets were used, which are detailed in the Appendix 1. Upper ocean profiles for temperature, salinity, DO, Chl-*a* and concentrations of dissolved inorganic nutrients (nitrate, phosphate, and silicate) were obtained, for evaluation in conjunction with a series of monthly Ekman upwelling estimates calculated from geostrophic wind data, obtained from the nearby Cape Columbine (Hutchings *et al*., 2012).

Table 1 St. Helena Bay Monitoring Line sampling station detail.

Station #	Latitude	Longitude	Bottom depth (m)	Distance from coast (km)
1	-32.299	18.302	27	3
2	-32.310	18.276	30	7
3	-32.330	18.177	76	17
4	-32.373	17.991	104	35
5	-32.413	17.808	150	53
6	-32.461	17.609	189	73
7	-32.505	17.422	235	92
8	-32.570	17.204	283	115
9	-32.604	16.986	311	134
10	-32.653	16.808	386	153
11	-32.699	16.620	564	172
12	-32.745	16.435	1 396	191

The periodicity of the S-N wind component off Cape Columbine (**Figure 8**) was produced by the reanalysis cooperative research project between the USA's NOAA National Center for Environmental Prediction (NCEP) and the National Science Foundation's National Center for Atmospheric Research (NCAR) and consists of four-times-daily (0:00, 06:00, 12:00, and 18:00 GMT) wind components on a 2.5° latitude × 2.5° longitude grid, downloaded from ftp://ftp.cdc.noaa.gov/pub/Datasets/ncep.reanalysis/surface, covering the period January 1948-present (Kalnay *et al*., 1996).

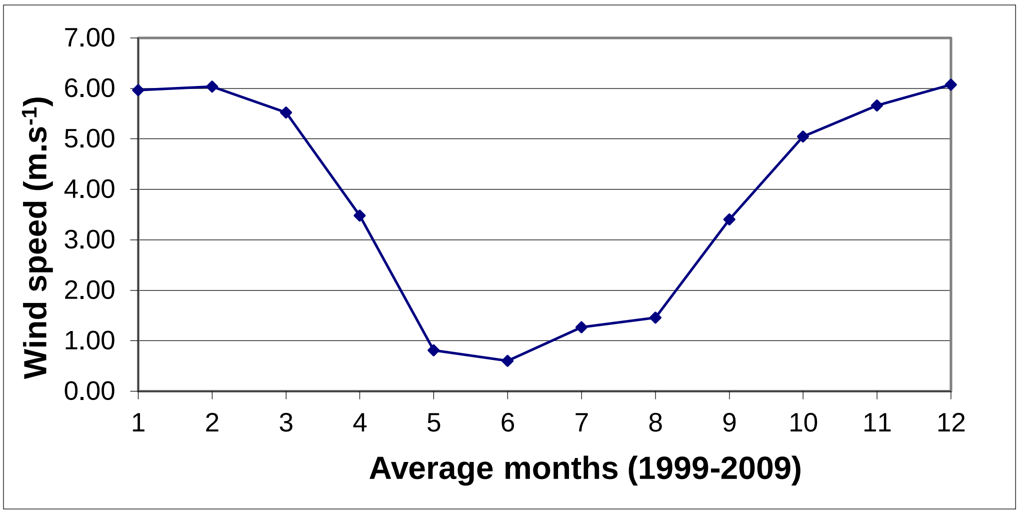


Figure 8 Averaged monthly Cape Columbine V-wind (S-N wind component) from 1999 to 2009.

3.2 Water Sampling and Analysis

Water samples were collected at the near surface (approximately 3 to 5 m depth) and deeper depths to within 5 m from the ocean seabed, using a 12 x 8 L Niskin bottle rosette sampler for water column profiling and discrete water sampling. Physical parameters were measured *in situ* using a Sea-Bird Electronics SBE 911 plus CTD (conductivity, temperature, and depth) sensor as well as fluorescence sensor. Water temperature was measured to an accuracy of ±0.001°C. The temperature gradient was used to indicate the presence or absence of a thermocline. Salinity was computed from CTD data in practical salinity units (PSUs) and calibrated using discrete samples (accuracy 0.0003 Siemens/meter). *In situ* data were quality checked which consists of modular, menu driven routines for converting, editing and processing of oceanographic data by using the SBE Seasave software, version 7.

Dissolved oxygen (DO) samples were collected in calibrated 100 ml iodine flasks and analyzed at sea by the modified Winkler method (Carpenter, 1965), using the equipment and procedure outlined by Hansen (1999) with an estimated precision of 0.02 ml/L. Once the water sample is collected, it is important to "fix" the sample immediately. Phytoplankton, bacteria, and other organisms in the sample can quickly change the oxygen content of the sample through photosynthesis and respiration. The first step of the Winkler method is the addition of 1 ml manganese chloride (a source of manganese ions) to the sample, quickly followed by the addition of 1 ml sodium hydroxide (a strong base) and potassium iodide (a source of iodine). In the presence of the strong base, each oxygen atom binds with a manganese ion to form a manganous hydroxide complex. This reaction creates a pale precipitate that will eventually sink to the bottom of the sample container. Concentrated hydrochloric acid (2 ml) is added to the solution to reduce the pH (range 1.5 - 2.5) and dissolve the precipitate. Through a series of chemical reactions, the O_2 combines with iodine to form a golden yellow chemical.

The final step of the dissolved oxygen measurement is a titration. Titration is a method of determining the concentration of a substance in a solution by adding a second chemical of a known concentration to produce a controlled chemical reaction. In the titration step, sodium thiosulfate is slowly added to the solution until all the iodine is neutralized (color disappears). We can determine how much iodine was in the solution from the amount of thiosulfate added. Furthermore, because each iodine molecule was produced by the reaction of a single oxygen atom, the amount of thiosulfate added also tells us how much oxygen was in the sample.

Steps in the Winkler method for dissolved oxygen determination:

1. Manganese (II) ions liberated from the manganese chloride are loosely bound with excess hydroxide.

$$Mn^{2+} + 2OH^{-} \rightarrow Mn(OH)_2 \tag{3}$$

2. Manganese (II) is oxidized to Manganese (III) in the presence of a strong base and binds the dissolved oxygen.

$$2Mn(OH)_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow 2Mn(OH)_3 \tag{4}$$

3. Free iodine is produced upon acidification of the sample at a rate of one I_2 molecule for each atom of oxygen.

$$2Mn(OH)_3^{-} + 2I^{-} + 6H^{+} \rightarrow 2Mn^{2+} I_2 + 6H_2O \tag{5}$$

4. Free iodine complexes with excess iodide ions.

$$I_2 + I^{-} \rightarrow I_3^{-} \tag{6}$$

The iodine/iodide complex is reduced to iodide with thiosulfate.

Samples for Chl-*a* analysis were taken at four depths (near-surface, above the fluorescence maximum (F-max), Fmax, and below the F-max). Subsamples (200 mL) of seawater for Chl-*a* analysis were collected in prerinsed plastic measuring cylinders. Samples were filtered under vacuum onto 25 mm Whatman GF/F glass fibre filter papers (Parsons *et al*., 1984). The filter papers were frozen in aluminium foil pouches for analysis ashore. Chl-*a* was measured fluorometrically on a Turner Designs 10-AU fluorometer after extraction in 90% acetone (Welschmeyer, 1994). The fluorometer was calibrated with Chl-*a* standard (Sigma Chemical Co., USA) in 90% acetone solution with a GBC Cintra 404 spectrophotometer and an extraction coefficient of 87.67 Lg^{-1} cm^{-1}.

Water samples for the study of dissolved inorganic nutrients were stored in acid-washed polyethylene bottles with pressure caps and kept frozen at -80°C until analysis ashore. No samples were kept frozen for longer than 3 months before analysis. Short term storage in this manner has a relatively minor effect on nutrient levels other than ammonium (Ryle *et al*., 1981). Because of the probability of contamination, samples for ammonium analyses need to be very fresh. This was not possible, so levels of ammonium are not included in this study. Dissolved nitrate (NO_3^-), phosphate (PO_4^{3-}), and silicates were determined according to the methods described by Grasshoff *et al*. (1983). The methods used were adaptations of standard methods and modified to the Astoria Analyzer system. Each method was calibrated using four known standards. An Astoria Analyzer Series 300 (**Figure 9**), which is a high precision, bench-top instrument for performing automated wet chemical analysis, expanded to four channels was used to perform the nutrient analysis. Based on a gas-segmented Continuous Flow Analysis (CFA) technique, invented in 1957 by Skeggs (Skeggs, 2000; Atlas *et al*., 1971), this system has evolved to become the method of choice for the determination of nutrients in seawater (Mee, 1986; Aminot and Kerouel, 2007). The Astoria can analyze single or multiple analyte concentrations at rates of up to 42 samples per hour at a sample-to-wash ratio of 2:1. Artificial seawater (ASW) is used in all methods for the purpose of standard dilution and as a blank. In order to obtain a more representative synthetic seawater, 32.125 g of sodium chloride, 7.125 g of magnesium sulphateheptahydrate and 0.168 g of sodium hydrogen carbonate are dissolved in Milli-Q water and made up to 1 L. The salinity of ASW is approximately 35 ppt.

Five primary components make up a CFA system**:** (1) Sampling device, (2) peristaltic pump, (3) reaction cartridge (manifold), (4) colorimeter and (5) data acquisition software. The analysis begins with the aspiration of the sample through a sample probe on the sampler. The sample is then pumped into a reagent stream flowing through the analytical cartridge. Flow rates for reagents, diluents and sample are precisely controlled (**Table 2)**. Since the analytical process can be quite long, air bubbles are injected into the stream to divide it into small segments. Air segmentation serves to minimize sample zone dispersion and carryover. As the sample progresses through the cartridge it may be diluted, mixed with other reagents, heated or subjected to other specific conditions necessary for the desired chemical reaction to occur. The chemical reaction usually results in the development of a colored product. The colored product is pumped through a flow-through cuvette (flowcell) mounted in a photometer. Therefore, in this case, the intensity of the “colour formation” is directly proportional to the concentration of the analyte during this analysis process. The photometer takes absorbance measurements and converts them to electronic analog signals. These signals are sent to a computer for processing.

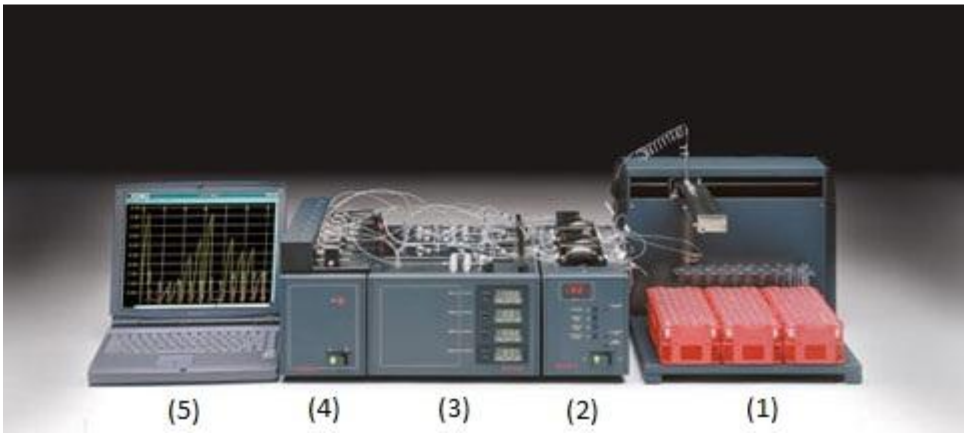


Figure 9 An Astoria Analyzer Series 300 system consisting of (1) Sampling device, (2) peristaltic pump, (3) reaction cartridge (manifold), (4) detector and (5) data acquisition computer.

3.2.1 Nitrate Method

A modification of the Armstrong (1967) procedure was used to measure nitrate plus nitrite. Nitrate was reduced quantitatively to nitrite by cadmium metal in the form of an open tubular cadmium reactor (OTCR). However, under some conditions reduction may proceed further with nitrite being reduced to hydroxylamine and ammonia. These reactions are pH dependent. Nitrogen was used to segment the analytical stream to prevent a pH increase due to reaction between oxygen in ambient air and cadmium; contact with oxygen will deactivate the OTCR. The nitrite thus formed and any originally present in the sample was determined as an azo dye at 540 nm following its diazotization with sulfanilamide and subsequent coupling with N-1-naphthylethylenediamine (**Table 2a**). These reactions take place in acidic solution. Nydahl (1976) provides a good discussion of nitrate reduction by cadmium metal. The process was then repeated without using the cadmium column to determine the original amount of nitrite in seawater. The concentration of nitrate in the sample was then determined by the following equation:

Nitrate = nitrate + nitrite (after reduction) - nitrite (before reduction) (7)

Nitrate stock standard solution (3750 µM): 0.37912 g Potassium Nitrate (KNO_3, FW 101.11) was dried at 110°C and dissolved in 900 ml Milli-Q water and diluted to 1.0 L with Milli-Q water. Three drops Chloroform ($CHCl_3$, FW 119.38) was added as preservative, mixed well and stored at 2 to 8°C. *Nitrate intermediate standard solution (375 µM)*: 10 ml of 3750 µM stock standard is diluted with ASW to 100 ml and mixed well. This was prepared weekly or as needed. Separate working standards were prepared by pipetting 26.67, 133.67, 2000 and 4000 µl of the intermediate standard into 50 ml volumetric flasks, which are made to volume with ASW. These working standards correspond to concentrations of 0.2, 1.0, 15 and 30 µM and made up daily or when running samples, for establishing linearity (**Figure 10a**). A schematic layout of the manifold is given in (**Figure 11a**).

At the buffered pH of the reactions, equation 8 predominates. However, if the cadmium surface is overly active; equation 9 will proceed sufficiently to give low results. If the cadmium surface is insufficiently active; there will be a low recovery of nitrate as nitrite, in equation 10. The latter is defined as poor reduction efficiency.

$$NO_3 + 2H^+ + 2e^- \rightarrow NO_2 + H_2O \qquad (8)$$

$$NO_2 + 6H^+ + 4e^- \rightarrow NO_3\,NOH^+ + H_2O \qquad (9)$$

$$NO_2 + 8H^+ + 6e^- \rightarrow NH_4^+ + 2H_2O \qquad (10)$$

To determine the reduction efficiency, a high level nitrite calibrant (16.88 µM) was run followed by a nitrate calibrant (16.88 µM) of the same nominal concentration. A reduction efficiency range of 90% to 100% is acceptable. The reduction efficiency was calculated as follows:

$$\text{Concentration } (NO_3) / \text{Concentration } (NO_2) \times 100\% = \%\ \text{Efficiency} \qquad (11)$$

3.2.2 Phosphate Method

Phosphate was analyzed using a modification of Bernhardt and Wilhelms (1967) technique (**Table 2b**). This method was used for the determination of phosphate in seawater and is applicable to many ranges. Ortho-phosphate reacts with molybdic acid to form phosphomolybdic acid. This complex was subsequently reduced with hydrazine to phosphomolybdous acid. The reaction product was heated to 70°C to enhance colour development and then passed through a 1 cm flowcell. Turbid samples were filtered before determination and absorbance was measured at 820 nm.

Phosphate stock standard solution (2500 µM): 0.3402 g Potassium Dihydrogen Phosphate (KH_2PO_4, FW 136.09) was dried at 110°C and dissolved in 900 ml Milli-Q water and diluted to 1.0 L with Milli-Q water, mixed well and stored at 2 to 8°C. *Phosphate intermediate standard solution (*100 *µM)*: 4 ml of 2500 µM stock standard was diluted with ASW to 100 ml and mixed well. This was prepared weekly or as needed. Separate working standards were prepared by pipetting 100, 250, 500 and 1500 µl of the intermediate standard into 50 ml volumetric flasks, which are made to volume with ASW. These working standards correspond to concentrations of 0.2, 0.5, 1.0 and 3.0 µM and made up daily or when running samples, again for establishing linearity (**Figure 10b**). A schematic layout of the manifold is given in (**Figure 11b**).

3.2.3 Silicate Method

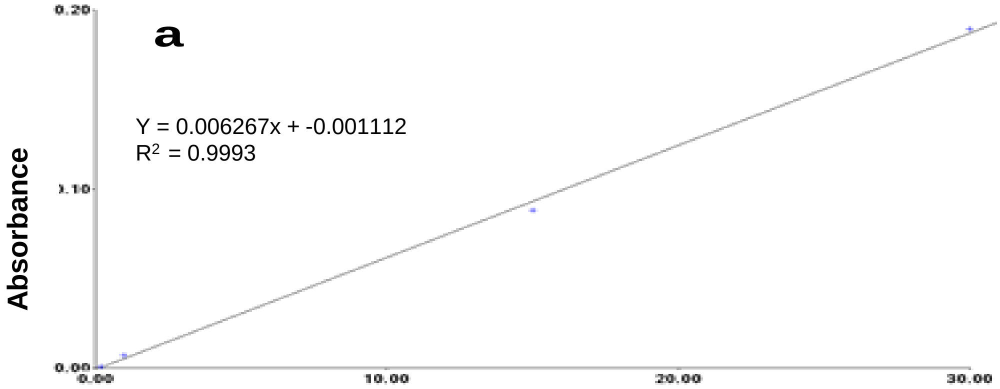
Silicate was analyzed using the technique of Armstrong (1967, **Table 2c**). This method was used for the determination of silicate in seawater and is applicable to many ranges. Silicomolybdic acid was formed by the reaction of silicate with molybdic acid. The silicomolybdic acid was reduced by stannous chloride to form molybdenum blue. Interference from orthophosphate and tannin was eliminated by the use of tartaric acid. The stream was then passed through a 1 cm flowcell and the absorbance measured at 820 nm.

Silicate stock standard solution (2500 µM): 0.4701 g Sodium Hexafluorosilicate (Na_2SiF_6, FW 188.06) was dried at 110°C and dissolved in 900 ml Milli-Q water. The solution was quantitatively transferred to a 1.0 L volumetric flask and diluted to 1.0 L with Milli-Q water. Two drops Chloroform ($CHCl_3$, FW 119.38) was added, mixed well and stored at 2 to 8°C. *Silicate intermediate standard solution (200 µM)*: 8 ml of 2500 µM stock standard was diluted with ASW to 100 ml and mixed well. This was prepared weekly or as needed. Separate working standards were prepared by pipetting 50, 250, 5000 and 10000 µl of the intermediate standard into 50 ml volumetric flasks, which are made to volume with ASW. These working standards correspond to concentrations of 0.2, 1.0, 20 and 40 µM and made up daily or when running samples, again for establishing linearity (**Figure 10c**). A schematic layout of the manifold is given in (**Figure 11c**).

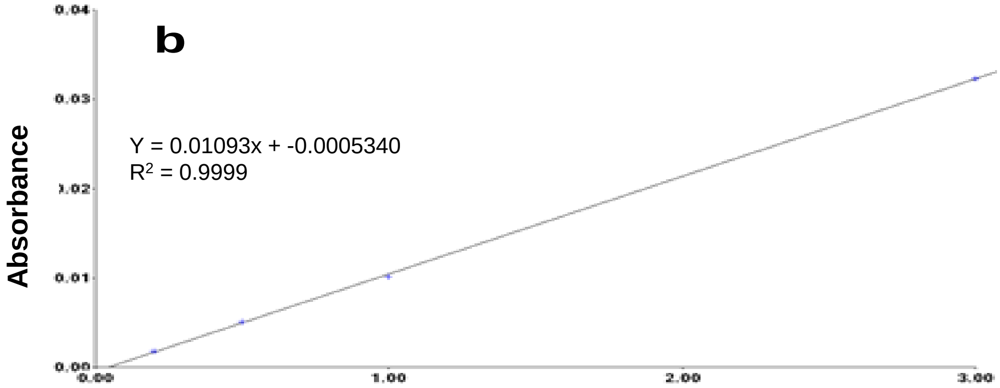
Table 2 Reagents used for (a) nitrate + nitrite (µmol/L), (b) phosphate (µmol/L) and (c) silicate (µmol/L) analysis.

	Reagent	**Flow rate (µl/min)**	**Component**	**Concentration**
a				
Nitrate	Sulfanilamide	74	$C_6H_8N_2O_2S$	10 g/L
			HCl	10%
			30% Brij-35	0.5 ml/L
	NED	74	$C_{12}H_{14}N_2$•2HCl	1.0 g/L
	Sample	385	n/a	n/a
b				
Phosphate	Molybdic acid	74	H_2SO_4	2.45 N
			$(NH_4)_6Mo_7O_{24}$•$4H_2O$	109 g/L
			SLS	15 g/85ml
	Hydrazine	74	Hydrazine sulphate	5.0 g/L
			SLS	15 g/85ml
	Sample	642	n/a	n/a
c				
Silicate	Molybdic acid	226	$(NH_4)_6Mo_7O_{24}$•$4H_2O$	10.8 g/L
			conc. H_2SO_4	2.8ml/L
	Tartaric acid	118	$H_2C_4H_4O_6$	200 g/L
	Stannous chloride	74	$SnCl_2$	50 g/100 ml
			HCl	1.2 N
	Sample	385	n/a	n/a

Nitrate + Nitrite



Phosphate



Silicate

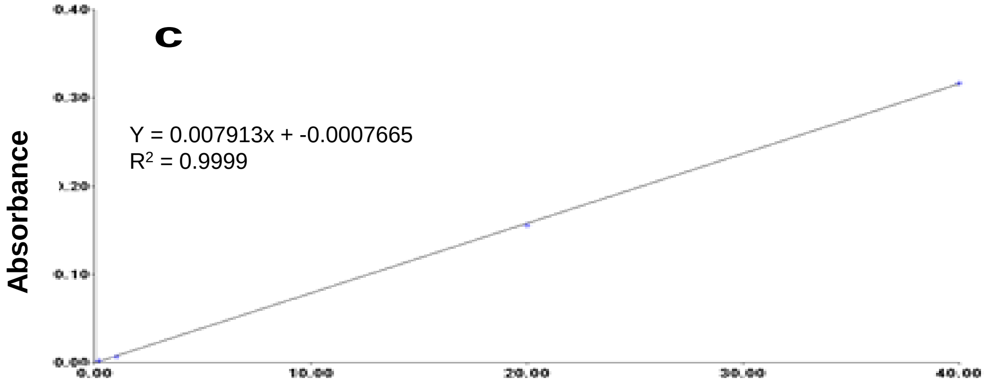


Figure 10 Averaged standard calibration curves for (a) nitrate + nitrite, (b) phosphate and (c) silicate in seawater for this time series.

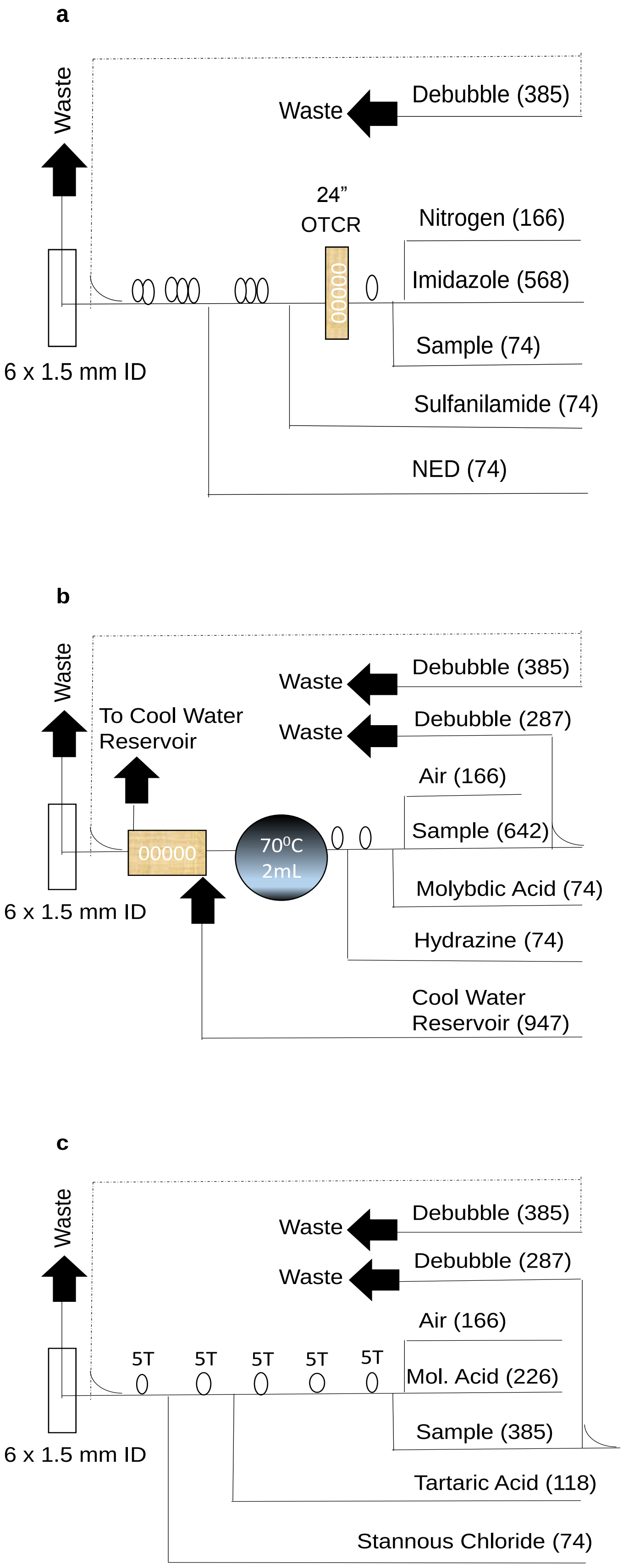


Figure 11 Manifold for the determination of (a) nitrate + nitrite, (b) phosphate and (c) silicate in seawater (values in parentheses denote the flow rate in μl/min, 0 = 5 turn coil and 5T = 25 turn coil).

3.2.4 Quality Assurance Programme

The quality assurance programme consisted of two separate related activities, quality control and quality assessment (Taylor, 1987). *Quality control (QC)* - is the system of activities whose purpose is to control the quality of a measurement so that it meets the needs of users. The aim is to ensure that data generated are of known accuracy to a stated, quantitative degree of probability. The outcome is the provision of data that is dependable. *Quality assessment (QA)* - is the system of activities that provide assurance that quality control is being done effectively. It provides a continuing evaluation of the quality of the analyses and of the performance of the analytical system.

The preparation of nutrient samples for laboratory analysis included proper packaging and providing appropriate QC/QA when submitting samples to ensure they do not become contaminated en route. The blank values are subtracted from standard and sample readings before any plots/calculations are made. To ensure reproducibility in nutrient measurements between analyses, a unique type of in-house standards were used, which were regularly compared to commercial products (OSIL). By inserting certified reference materials (CRMs) in sample sets, the results from CRMs can be compared to the expected values to assess the accuracy of the analytical values for the unknown samples. Precision was also tested, and it is for this reason that an inter-laboratory comparison (I/C) was conducted for the analysis of nutrients (nitrate, phosphate and silicate) in seawater samples. Samples were collected in 2006 at standard depths on the east coast of South Africa, filtered through 0.45µm membrane filters and immediately pasteurized. The samples were stored in the dark for analysis ashore. To test the homogeneity and stability of these nutrients, one set of samples were sent to a laboratory in Brest (BR), France and a second set sent to our laboratory in Cape Town (CT), South Africa. This I/C conducted for the first time, provided an opportunity to assess and improve laboratory performance, thereby, improving the quality of the analytical data. Each laboratory participated as if the analyses were performed as a result of normal operations; that is, a single concentration value was reported by each laboratory for each nutrient in each seawater sample. To ensure a consistency in reporting, all values were converted to concentration of micromoles per litre. In the analytical approach adopted here for seawater samples – both methods were considered properly validated by the individual analysts.

3.3 Method of Approach

3.3.1 Inshore Time Series

The Cape Columbine upwelling series was derived for the cell centered on 32.5°S, 16.5°E with a coastline orientation of 180°. Since it was assumed that oceanographic conditions on the

SHBML would be influenced by upwelling in the Cape Columbine upwelling cell, the average monthly SST fields, for the months December to April, in the vicinity of SHB was examined and it was clear that stations 2 to 5 were most directly, and most frequently influenced (**Figure 5**). Therefore, for purposes of this thesis, time series surface data of the averages of these four stations is presented.

3.3.2 Offshore Time Series

Later, it was considered that upwelling at Cape Columbine might have an immediate effect in the path of the offshore stations in a north-northwesterly direction. It is for this reason that correlations were performed on averages of time series surface samples collected on stations 7 to 10 (**Figure 5**) just outside the bay to clarify this.

3.3.3 Linear Lagged Time Series

In order to gain insight into the effect upwelling has on the surface waters in SHB, linear lagged correlations were carried out using surface data collected on the SHBML. Upwelling vertical velocity was estimated using a drag coefficient for 3 m/s ≤ W < 10 m/s due to Ekman upwelling at Cape Columbine. At the coast, the cross-shore transport is zero and it increases to the Ekman transport, $\tau/\rho f$, approximately R_{bc} km from the coast using the following definitions.

$$f = 2\ \omega \sin(\phi) \quad \text{at Cape Columbine} \tag{12}$$

$$\text{Wind stress } (\tau) = \rho_a C_d W^2 \tag{13}$$

The internal (barotropic) Rossby radius of deformation $(R_{bc}) = c_i/f \approx NH/f$

$$c_i = NH = 0.6 \text{ m/s, therefore} \quad R_{bc} = 7.6 \text{ km} \tag{14}$$

$$\text{Ekman transport} = \tau/\rho f = 0.0825/(1000 \times 0.7906 \times 10^{-4}) \tag{15}$$

Therefore:

$$\text{Upwelling velocity} = (\tau/\rho f)/R \tag{16}$$

Lagged correlations were carried out using the SHBML data as the dependent variables (y-variables) and QuickSCAT S-N wind speed on the SHBML sample date as well as 10 days prior to the sample date. In other words, for each of the 7 oceanographic parameters, 11 linear regressions were performed representing lags 0-days, 1-day, 2-days, etc., to a lag of 10 days. The maximum lag of 10 days was chosen so as to encompass a complete wind event cycle, which according to **Table 3** ranges, on average, between 7.7 and 8.6 days.

Table 3 Monthly average and standard deviation (SD) data produced (1949 to 2009) for the S-N wind component off Cape Columbine.

Month	Average peak to peak period (days)	SD of the period (days)	Average wind speed peak value (m/s)	SD of the wind speed peak value (m/s)	Average wind speed minimum value (m/s)	SD of the wind speed minimum value (m/s)
1	8.4	3.67	7.7	1.96	4.1	2.43
2	8.5	3.70	7.5	1.92	4.0	2.38
3	8.6	4.01	6.4	2.07	2.8	2.52
4	8.3	4.10	4.6	2.45	0.8	2.92
5	8.3	3.84	2.6	2.67	-1.5	2.98
6	7.9	3.84	1.6	2.43	-2.4	2.76
7	7.7	3.69	1.7	2.35	-2.4	2.73
8	7.9	3.68	2.7	2.73	-1.6	2.92
9	8.2	3.44	4.3	2.64	0.0	2.92
10	8.1	3.62	5.9	2.34	1.8	2.95
11	8.2	3.65	6.9	2.25	3.2	2.87
12	8.5	3.55	7.4	2.11	3.7	2.69

It was considered that the effect of upwelling might vary from (1) winter (May to August) when upwelling is at a minimum to (2) early summer (October to December) when upwelling is intensifying and to (3) late summer (January to March) when upwelling is fully developed. The data set was therefore partitioned into these three seasons and separate sets of lagged correlations performed for each.

It was also considered that upwelling at Cape Columbine might have a more immediate effect on that part of the SHBML line outside the bay, and therefore directly in the path of the north-northwestwards advected upwelling plume, than the part of the line inside the bay. For this reason, lagged correlations were performed on two data sets: (1) composed of the averages of the samples collected on stations 2 to 5 inside the bay (station 1 was regarded as being in too shallow water) and (2) averages of samples collected on stations 7 to 10 just outside the bay.

Therefore, from seven parameters, on two sets of stations, in three seasons, 42 sets of lagged correlations were obtained where each set consists of the slope, constant, correlation coefficient, statistical F-test parameter and significance of the correlation based on the F-test parameter.

Chapter 4

Results and Discussion

4.1 Results of analytical precision of participating laboratories for analyses of nutrients

Despite the fact that there is probably no simple way to ascertain whether the system blank is biased or not, allows us to have a strong conviction that our blank determinations are correct at least for nitrate, phosphate and silicate. At the given precision of the blank (see **Table 4**), no significant negative values were ever encountered. During the present exercise, 42 system blanks have been performed at various periods in 2006. Their values are 0.022 ± 0.009 μmol/L for NO_3^-, 0.019 ± 0.012 μmol/L for PO_4^{3-} and 0.075 ± 0.013 µmol/L for Si, respectively. Given this satisfying stability (± 0.01 μmol/L) over this working period, the blank was considered unbiased.

For silicate, the RSD is < 0.2 % at high level, < 1.2 % at low level for nitrate and < 2.8 % at low level for phosphate (in-house standards). For the CRMs, the RSD is < 0.1 % for silicate at high level, and similar for nitrate and phosphate at low level. For the calculation of total standard deviations, these values have been considered as the confidence interval at 95 % probability, which implies a relative standard deviation of ± 0.5 %. Therefore, it is quite evident that the use of CRMs, is essential to establish and improve the comparability of nutrient data of the world's oceans.

Results from the lab-based I/C exercise on 3 subsamples, which had been stored for ~6 months, showed excellent agreement between the two participants. Mean concentrations for NO_3^- of 21.10 ± 5.92 and 23.38 ± 6.55 μmol/L, PO_4^{3-} of 1.59 ± 0.46 and 1.84 ± 0.50 μmol/L, and Si of 23.03 ± 16.86 and 24.98 ± 16.58 μmol/L (n = 3) were obtained for CT and BR, respectively (**Table 4**). Although this is an important result, it may be necessary in order to achieve better comparable results for the measurement of “dissolved” nutrients using more than two participants in future. The outcome of ongoing I/C studies using seawater samples are expected to provide further information in this regard.

Table 4 Assigned concentrations for nitrate, phosphate and silicate (confidence level = 95 %). System blanks as determined using an Astoria Analyzer Series 300. The blanks are converted into their equivalent in micromoles per litre of the corresponding nutrients. Concentrations of nutrients in the samples: measured values in micromoles per litre. The storage time for the I/C samples was ~6 months. SD = standard deviation and n = number of replicate samples.

Blank	**Nitrate**	**Phosphate**	**Silicate**
Mean	0.022	0.019	0.075
SD	0.009	0.012	0.013
n	42	42	42
In-house	**Nitrate**	**Phosphate**	**Silicate**
Mean	0.20	0.41	40.04
SD	0.01	0.00	0.05
n	5	5	5
CRMs	**Nitrate**	**Phosphate**	**Silicate**
Mean	0.17	0.37	26.80
SD	0.00	0.00	0.02
n	5	5	5
CT	**Nitrate**	**Phosphate**	**Silicate**
Mean	21.10	1.59	23.03
SD	5.92	0.46	16.86
n	3	3	3
BR	**Nitrate**	**Phosphate**	**Silicate**
Mean	23.38	1.84	24.98
SD	6.55	0.50	16.58
n	3	3	3

4.2 Inshore and Offshore Relationships

4.2.1 Relationship between the UI and Sea-Surface Temperature and Salinity

Temperature and salinity variations at the near-surface (**Figures 12(a)** and **12(c)**) and 20 m depth (**Figures 12(b)** and **12(d)**) for the period 2004 to 2009, at stations 1 (inshore) to 12 (offshore), were evaluated in the context of an upwelling index calculated from geostrophic wind data (black line in **Figures 12(a)** and **12(b)**). The upwelling index (UI) starts to increase in late winter (August), in response to increased south-easterly trade winds, which cause surface Ekman transport in a northwesterly direction and coastal upwelling. The productivity stimulated by the increased availability of nutrients that result from this upwelling is what makes St. Helena Bay one of the most productive areas in the Southern Benguela Upwelling system. As the wind regime changes over from summer (December to February) south-easterlies to predominantly westerly winds in winter (June to August), a relative brief period of downwelling occurs.

On a shelf-wide scale, clear gradients in temperature and salinity are evident, with both parameters increasing with distance offshore. Temperature increases from as low as 9.8°C at the coast (3 km offshore) to almost 22°C offshore (191 km from coast) at the near surface and from 9.34 to 20.61°C at 20 m depth (**Figures 12(a)** and **12(b)**). Salinity values increased from 34.41 at the coast to 35.60 PSU offshore at the near surface and from 34.68 to 35.60 PSU at 20 m depth (**Figures 12(c)** and **12(d)**). At first glance, it appears that near-surface temperature in St. Helena Bay exhibits seasonal variability, with winter (June to August) temperature 2 to 3°C warmer than that observed during the spring (September to November) to late summer (February) upwelling season at both the inshore and offshore stations (**Figures 12(a)** and **12(b)**). Closer inspection of the near surface data at the more frequently sampled inshore stations, however, reveals that every year contains exceptions to this generalized seasonal trend (**Figure 13(a)**): there were warm water events outside the “regular” winter (June to August) period during late summer (February) in 2004, summer (December to February) in 2005, late summer (February) and spring (September to November) in 2006, late spring (November) in 2007, summer (December to February) in 2008, and late summer (February) and spring (September to November) in 2009. These warm water events are usually, but not always, also observed at 20 m depth (**Figure 13(a)**).

Table 5 Linear regression coefficients (slopes) for physical and chemical variables as a function of the upwelling index, at the surface (3 to 5 m) and 20 m sampling depths, for stations 1 to 12. Bold values indicate slopes that are significant at $P < 0.01$.

	Temp.	Salinity	O_2	NO_3^-	PO_4^{3-}	Si	Chl-*a*
3 to 5 m							
St # 1	-0.0031	-0.0002	-0.0072	0.0215	0.0039	0.0457	0.0328
2	-0.0012	-0.0004	-0.0028	0.0134	**0.0067**	0.0632	0.0139
3	0.0008	**-0.0007**	0.0017	-0.0106	0.0034	0.0353	0.0308
4	-0.0002	**-0.0009**	0.0028	-0.0098	0.0014	-0.0108	0.0301
5	-0.0003	**-0.0014**	0.0031	-0.0098	0.0007	-0.0153	**0.0488**
6	0.0013	**-0.0017**	0.0038	-0.0104	-0.0002	-0.0149	**0.0307**
7	0.0029	**-0.0016**	0.0024	-0.0148	-0.0011	-0.0245	0.0285
8	0.0029	**-0.0017**	0.0024	-0.0094	-0.0022	**-0.0214**	**0.0251**
9	0.0064	-0.0009	-0.0009	-0.0016	-0.0011	-0.0139	0.0116
10	0.0068	-0.0011	-0.0004	-0.0056	-0.0011	**-0.0159**	**0.0158**
11	**0.0141**	0.0000	-0.0019	**-0.0103**	**-0.0023**	-0.0151	0.0057
12	**0.0158**	0.0002	-0.0039	-0.0064	-0.0017	-0.0097	-0.0016
20 m							
St # 1	**-0.0169**	**-0.0005**	**-0.0189**	**0.0581**	**0.0064**	0.0624	0.0233
2	**-0.0197**	**-0.0005**	**-0.0230**	**0.0783**	**0.0099**	**0.1011**	0.0306
3	**-0.0162**	**-0.0007**	**-0.0166**	**0.0714**	**0.0077**	**0.0772**	**0.0437**
4	**-0.0167**	**-0.0009**	**-0.0098**	**0.0629**	**0.0048**	0.0099	0.0454
5	**-0.0142**	**-0.0017**	**-0.0088**	0.0379	0.0038	-0.0007	0.0309
6	-0.0071	-0.0013	-0.0033	0.0273	0.0021	0.0069	**0.0248**
7	-0.0040	**-0.0015**	-0.0031	0.0155	0.0016	-0.0079	**0.0349**
8	-0.0063	**-0.0016**	-0.0032	-0.0007	-0.0001	-0.0168	**0.0248**
9	0.0011	-0.0009	-0.0020	-0.0082	0.0004	-0.0120	0.0317
10	-0.0016	**-0.0015**	-0.0015	0.0105	0.0001	-0.0135	0.0142
11	**0.0153**	0.0002	-0.0028	-0.0093	0.0004	-0.0213	0.0029
12	0.0129	0.0000	-0.0032	-0.0097	**-0.0019**	-0.0072	0.0022

Linear regression coefficients between temperature and the upwelling index, which has a very well defined seasonal profile (black line in **Figures 12(a)** and **12(b)**), confirm the poor seasonality visually evident in the near-surface temperature data (**Table 5**). The expected trend is for surface temperature to decrease in response to upwelling (more positive UI values) and for this to be more pronounced closer to shore, where divergence is more likely to occur. However, near-surface temperature is observed to be very poorly correlated with the UI at the surface (approximately 3 to 5 m depth), except at the furthest offshore stations (11 and 12), where a weak positive correlation with the UI is observed. At 20 m depth the expected negative relationship between temperature and the UI is evident at stations 1 to 5 (inshore stations), with again a positive relationship with the UI manifesting at the offshore stations (11 and 12), with the latter slightly weaker than the correlation at the near surface.

There is a more pronounced relationship between the UI and near-surface salinity at the inshore stations than observed for temperature (**Table 5, Figures 12(c)** and **12(d)**). The data suggests a trend of decreasing salinity values at times of upwelling, at both the near-surface and 20 m depth, slightly better expressed at 20 m depth. Seasonal variations in salinity are well-defined from 2004 to 2006 (**Figure 13(b)**). In 2007, however, the seasonal profile is disrupted by the intrusion of a water mass with typical winter time (June to August) temperature (13.16°C) but much lower salinity (34.41 PSU) values than is the norm in July (**Figure 13**), followed by a return to more typical upwelling conditions the following month, that is, colder (11.24°C) more saline (34.80 PSU) water. Similar but less pronounced intrusions of water masses with lower salinities than normally observed in winter (June to August) disrupt the seasonal salinity profiles in 2008 and 2009 (**Figure 13(b)**). These fresher-water intrusions are also much more evident at near-surface sampling depths than at 20 m depth and in 2008, for example, it is only evident at the near surface.

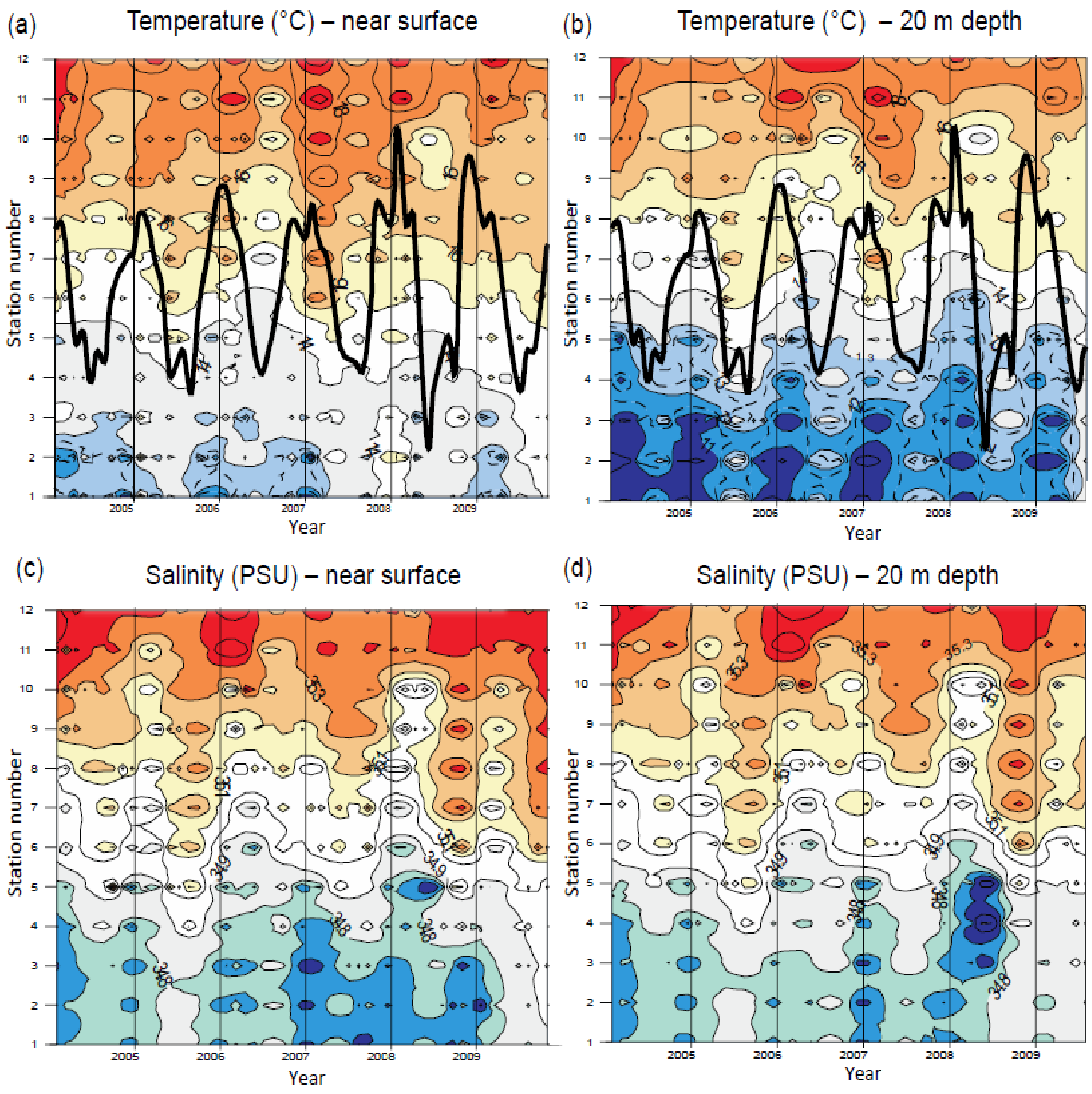
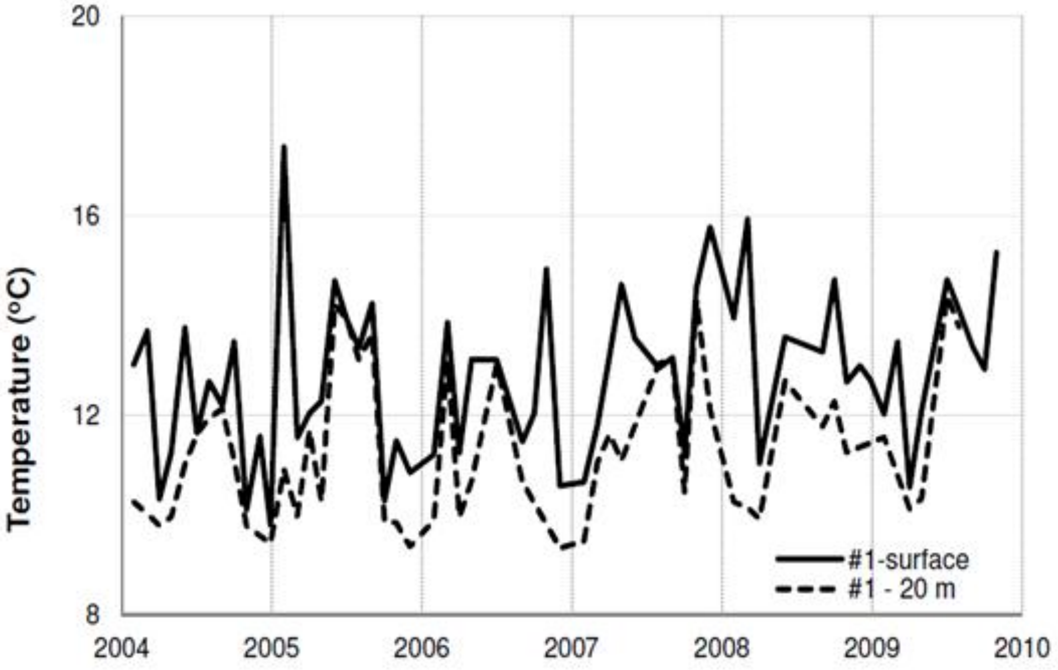


Figure 12 Inshore-offshore near-surface (a and c) and 20 m depth (b and d) variability over time for temperature (a and b) and salinity (c and d). The thick black line represents the upwelling index (UI). Temperature (°C) and salinity (PSU) values are indicated as labels on

respective isobars. The temperature ranged between <11°C (dark blue) and >18°C (red). Salinity ranged between <34.7 PSU (dark blue) and >35.4 PSU (red).

a



b

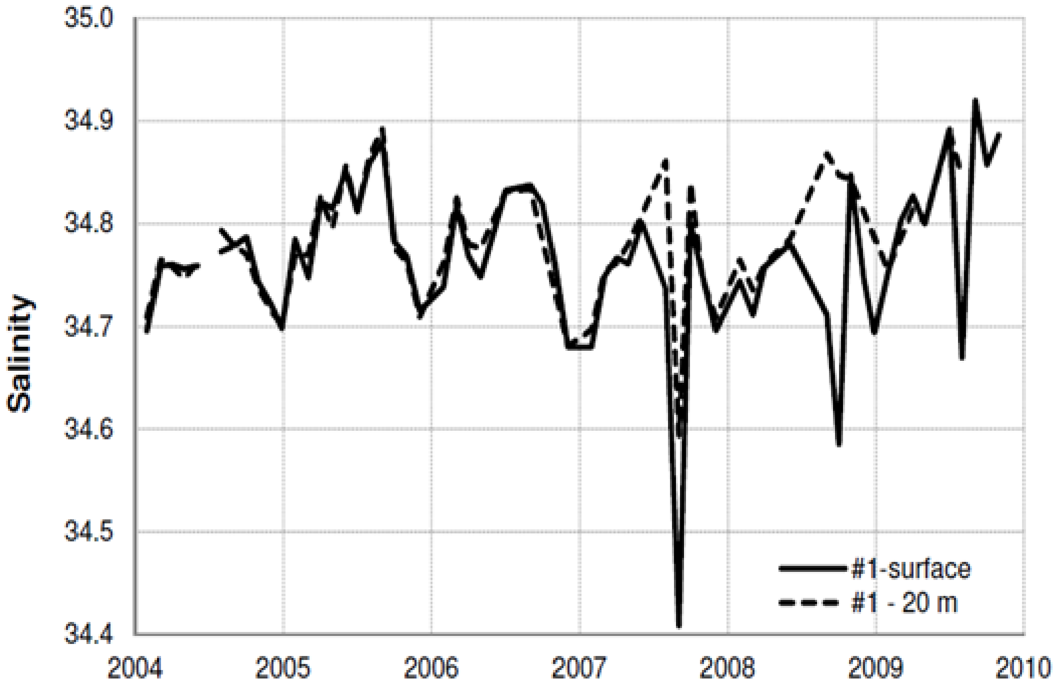


Figure 13 Temporal changes in (a) temperature and (b) salinity at station 1, near surface and at 20 m depth.

4.2.2 Relationship between the UI and Surface Ocean Nutrient and Chlorophyll-a Concentrations

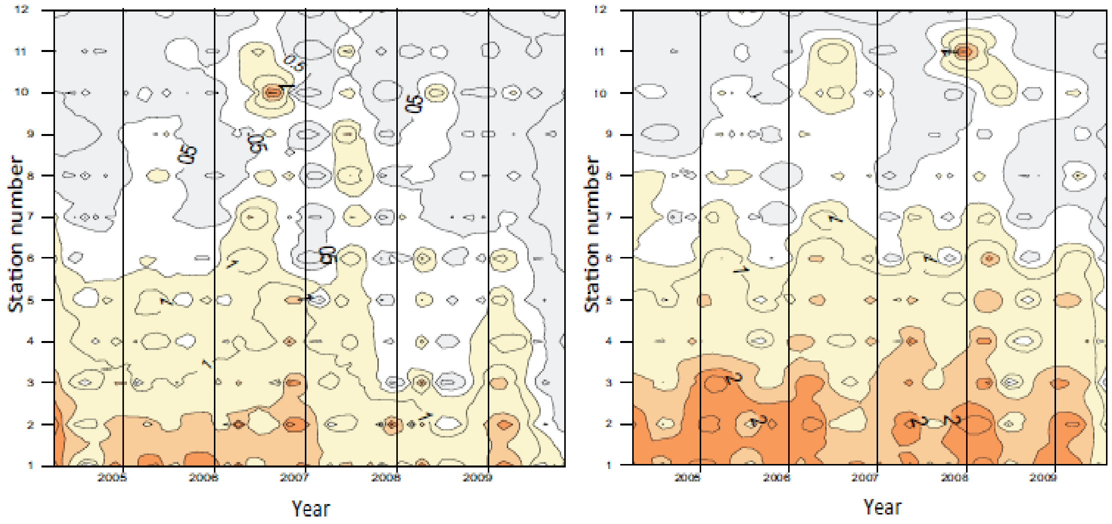
Near-surface ocean distribution patterns for nutrients exhibit across-shelf gradients, from high values along the coast (up to 26.5 μmol/L for NO_3^-, 4.16 μmol/L for PO_4^{3-}, and 46.8 μmol/L for Si) to offshore near-surface values that are typically lower by a factor of 10 as expected in a coastal upwelling area (shown for PO_4^{3-} in **Figures 14(a)** and **14(b)**). This inshore-offshore gradient in nutrient availability is reflected in higher inshore Chl-*a* levels (above 40 mg/m^3 in some instances), that is, enhanced coastal productivity fuelled by the higher availability of nutrients (**Figures 14(c)** and **14(d)**). There is a general trend of lower nutrient and Chl-*a* values during the winter (June to August) along the SHBML and higher nutrient and Chl-*a* during the upwelling season (**Figures 14** and **15**). However, similar to the observations made for temperature, the annual cycles are disrupted by numerous events, during which nutrient and Chl-*a* levels are contrary to this generalized view of surface ocean nutrient dynamics. The result is variability that exhibits very poor seasonality (**Figure 15**). The relationship between the UI and the nutrient parameters dissolved NO_3^-, PO_4^{3-}, and Si is very weak at the near surface but is slightly better expressed at 20 m depth, where the relationship with the UI is positive, as expected in a upwelling area (**Table 5, Figures 14(a)** and **14(b)**). Of the three nutrient proxies, PO_4^{3-} shows the strongest relationship with the UI (**Table 5**). Chl-*a* levels exhibit a weak but positive relationship with the UI at both sampling depths and all stations (**Table 5, Figures 14(c)** and **14(d)**).

Nutrient and Chl-*a* variability associated with the warm water events that disrupt the seasonal temperature profile, and the fresher water events that disrupt the seasonal salinity profile, bear further scrutiny. The anomalous warm water events observed at station 1 in the summer (December to February) of 2005, the summer (December to February) of 2006, late spring (November) in 2007, and in spring (September to November) in 2009 are all characterized by much lower than usual surface nutrient levels (0.17 to 2.41 μmol/L for NO_3^- and 0.26 to 1.21 μmol/L for PO_4^{3-}). The most pronounced of these, during the summer (December to February) of 2005 was also associated with very high Chl-*a* levels (33.4 mg/m^3) and temperature-salinity properties (T = 17.38°C and S = 34.79 PSU) that rule out the intrusion of an offshore warm-nutrient-depleted water mass (**Figure 12**) as an explanation for this event. The high temperature suggests thermal heating as the cause of the elevated temperature, and the low nutrient and high Chl-*a* levels suggest the existence of an algal bloom, caused by the existence of stratified conditions conducive to enhanced phytoplankton productivity. The combined temperature-salinity-nutrient-Chl-*a* properties that characterize the other warm water events that are evident in the temperature record (**Figure 13(a)**) are more ambiguous. Although conditions similar to those which appear to have caused the summer (December to February)

2005 warm event cannot be ruled out, such conditions also cannot be confirmed with the data available.

The most pronounced low-salinity event observed occurred in the winter (June to August) of 2007 (**Figures 12(c)** and **13(b)**).The temperature, nutrient, and Chl-*a* levels associated with this event, however, are not unusually high or low, with the exception of lower than usual dissolved Si levels (5.42 µmol/L). An explanation for the origin of the low salinity water observed in early spring (September) in 2008 and later winter (August) 2009 is also difficult to extract from the available data. Although continental run-off from winter (June to August) rainfall over the adjacent landmass cannot be ruled out as a contributing factor, there is nothing in the data available to substantiate such a hypothesis at this stage.

(a) Dissolved phosphate (µmol/L) – near surface (b) Dissolved phosphate (µmol/L) – 20 m depth



(c) Chl-*a* (mg/m³) – near surface (d) Chl-*a* (mg/m³) – 20 m depth

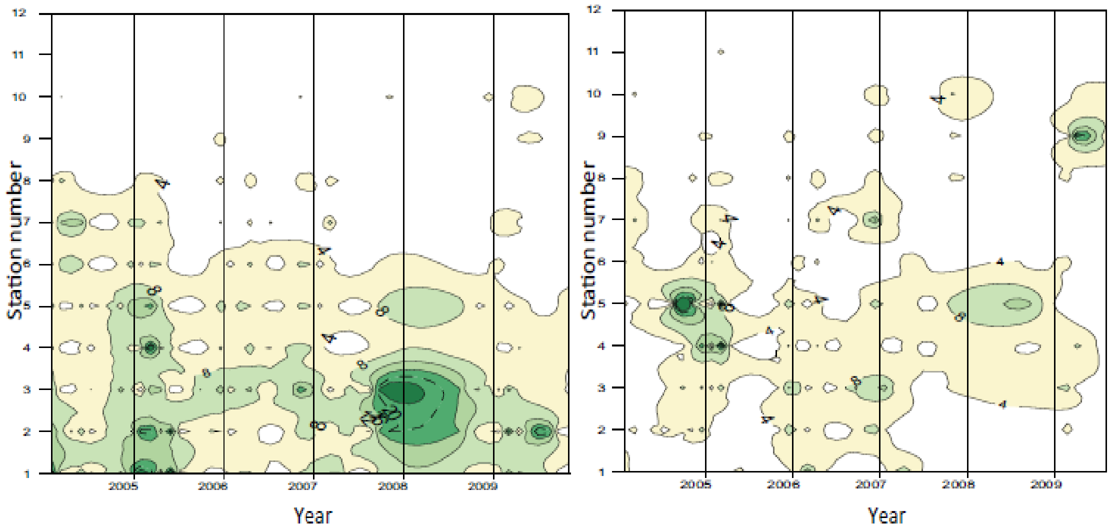
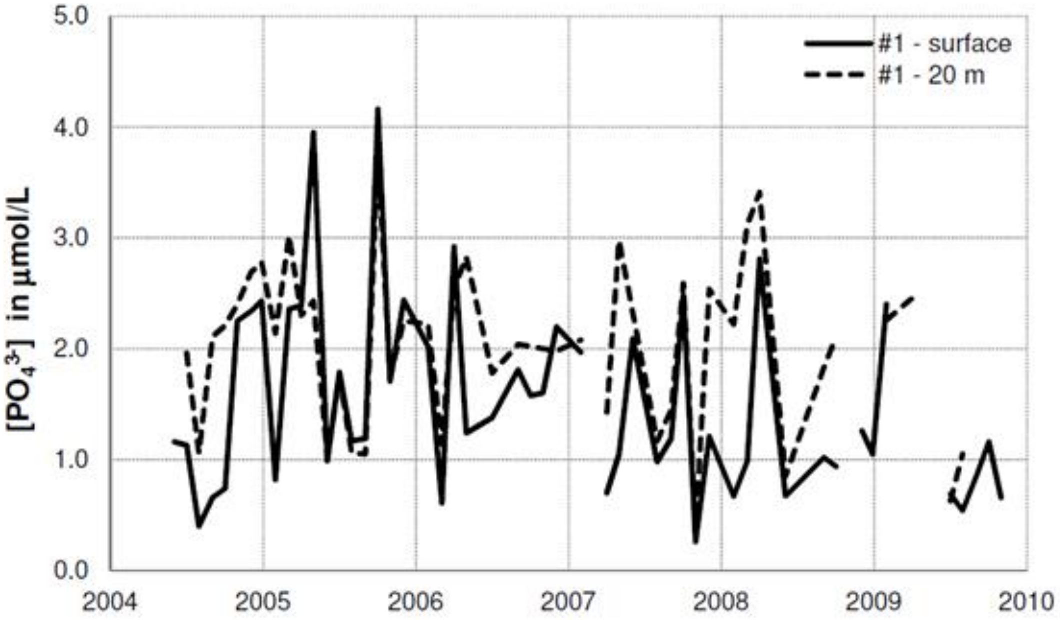


Figure 14 Inshore-offshore near-surface (a and c) and 20 m depth (b and d) variability over time for dissolved phosphate (a and b) and Chl-a (c and d). Dissolved phosphate (µmol/L) and

Chl-*a* (mg/m^3) values are indicated as labels on respective isobars. The dissolved phosphate ranged between <0.5 µmol/L (grey) and >2 µmol/L (dark orange). Chl-*a* ranged between <4 mg/m^3 (white) and >20 mg/m^3 (dark green).

a



b

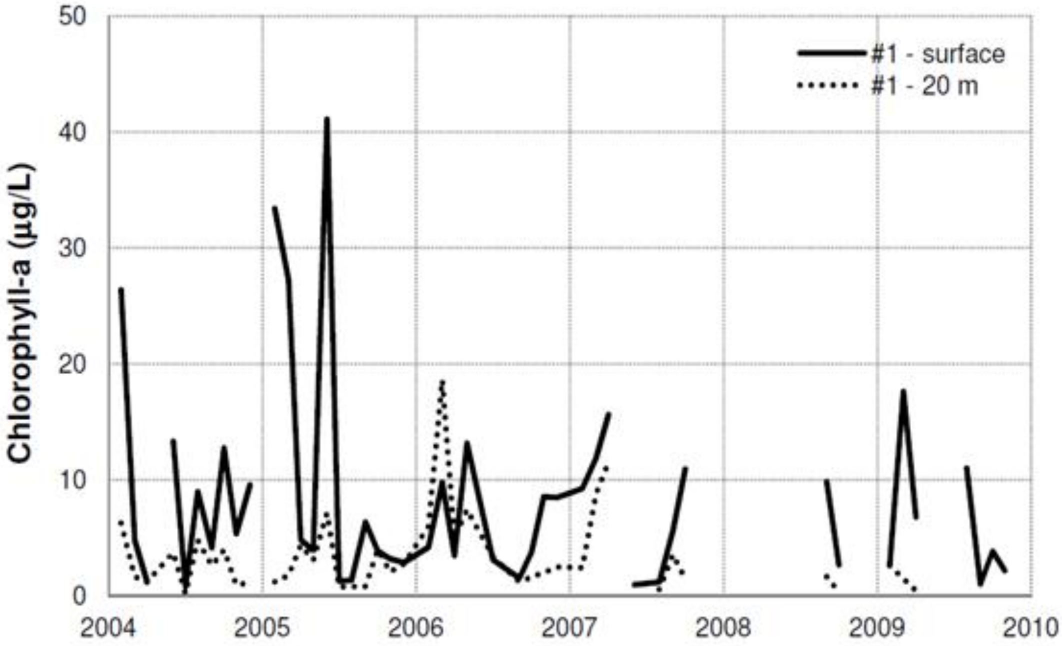


Figure 15 Temporal changes in (a) dissolved phosphate (PO$_4^{3-}$) and (b) Chl-*a* at station 1 near surface and at 20 m depth.

4.2.3 Relationship between the UI and Vertical Temperature and Nutrient Gradients

Evaluation of variability in the upper ocean temperature gradient (shown for station 1 in **Figure 16**), in comparison with seasonal variability in the upwelling index, shows that the temperature gradient exhibits better defined seasonal variability than surface ocean temperature. Along the SHBML the water column is more stratified during spring (September to November) and summer (December to February) than during the winter (June to August). Generally speaking, surface temperatures and surface-deep water temperature gradients are determined by a balance between surface heating and wind induced vertical mixing. Along the SHBML the net surface heat flux is positive and is increasing during the spring-summer upwelling season. The water column stabilization and stratification that result from this counter the tendency for vertical mixing induced by upwelling-favorable winds during the spring-summer season, during most years (**Figure 16**). During the winter (June to August) the water column is better mixed, despite the prevailing downwelling-favorable winds during this season. The balance between surface heating and vertical mixing is clearly in favor of surface heating in SHB. This has implications not only for the application of remote sensing methods to track upwelling events, but also for biological processes and spatial and temporal variability therein. Planktonic organisms tend to be distributed throughout the water column when it is well mixed, which is winter-time along the SHBML. When the water column is stratified, that is, spring-summer along the SHBML, it favors the development of algal blooms. Also, this concentration of food particles in a stratified water column is believed to be advantageous to the growth of larval fish (Buckley and Lough, 1987).

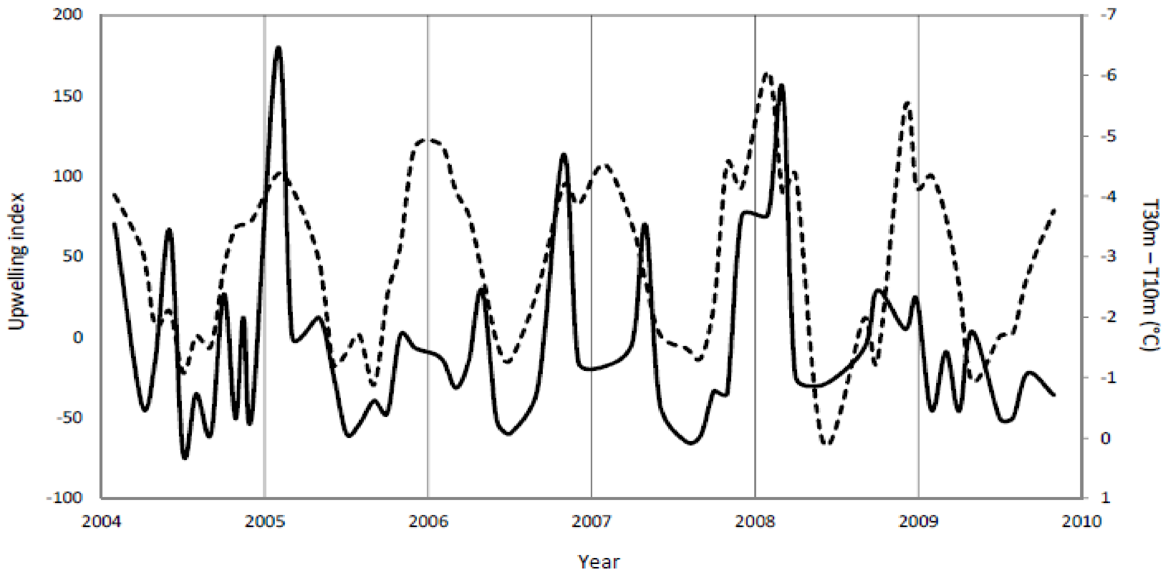


Figure 16 Variability in the upwelling index (dashed line) versus the temperature difference between 30 and 10 m depths (solid line), at station 1, for the time period 2004 to 2009.

4.2.4 Seasonal Vertical Relationships at Station 11

The front extends sometimes offshore past station 11 in powerful upwelling and at other times an offshore eddy exists at this station or even station 12, so occasionally the water turns green according to L. Hutchings (pers. comm.). However, the norm is that station 11 is in South Atlantic Surface Water (SASW) or Agulhas Bank Surface Water (ABSW), with little differentiation in temperature or salinity. Oceanic water away from the influence of the Agulhas water should have a seasonal difference in temperature of about 4 to 5°C, which in this case is 3.02°C (**Figure 17a**). The change in salinity at the surface from winter to late summer ranges from 35.35 to 35.40 PSU (**Figure 17b**). Oxygen at the surface varies between narrow limits, 4.70 to 5.01 ml.L^{-1} (**Figure 17c**), and probably related to high phytoplankton densities at the Chl-*a* subsurface maxima in summer. The Chl-*a* concentration (generally low offshore) is low in winter, rises in early summer as the widespread spring bloom occurs and subsurface maxima occur, indicating nutrient depletion at the surface and a supply of nutrients through the thermocline by diffusion and perhaps shear effects. Concentrations of Chl-*a* maximum exceeded 1.6 mg/m^{-3} at both 10 m (early summer) and subsurface (30 m, late summer), clearly associated with the frontal system and jet current offshore of Cape Columbine. Equally pronounced Chl-*a* minimum at 20 m is visible during late summer (**Figure 17d**). When there is a cyclonic eddy or an offshore extent of the front the nutrients are enhanced but quickly reduced by phytoplankton growth so generally are low. The relative decrease in nitrate with depth is faster than silicate or phosphate, reflecting a preferential demand for nitrate (**Figure 17e, f & g**).

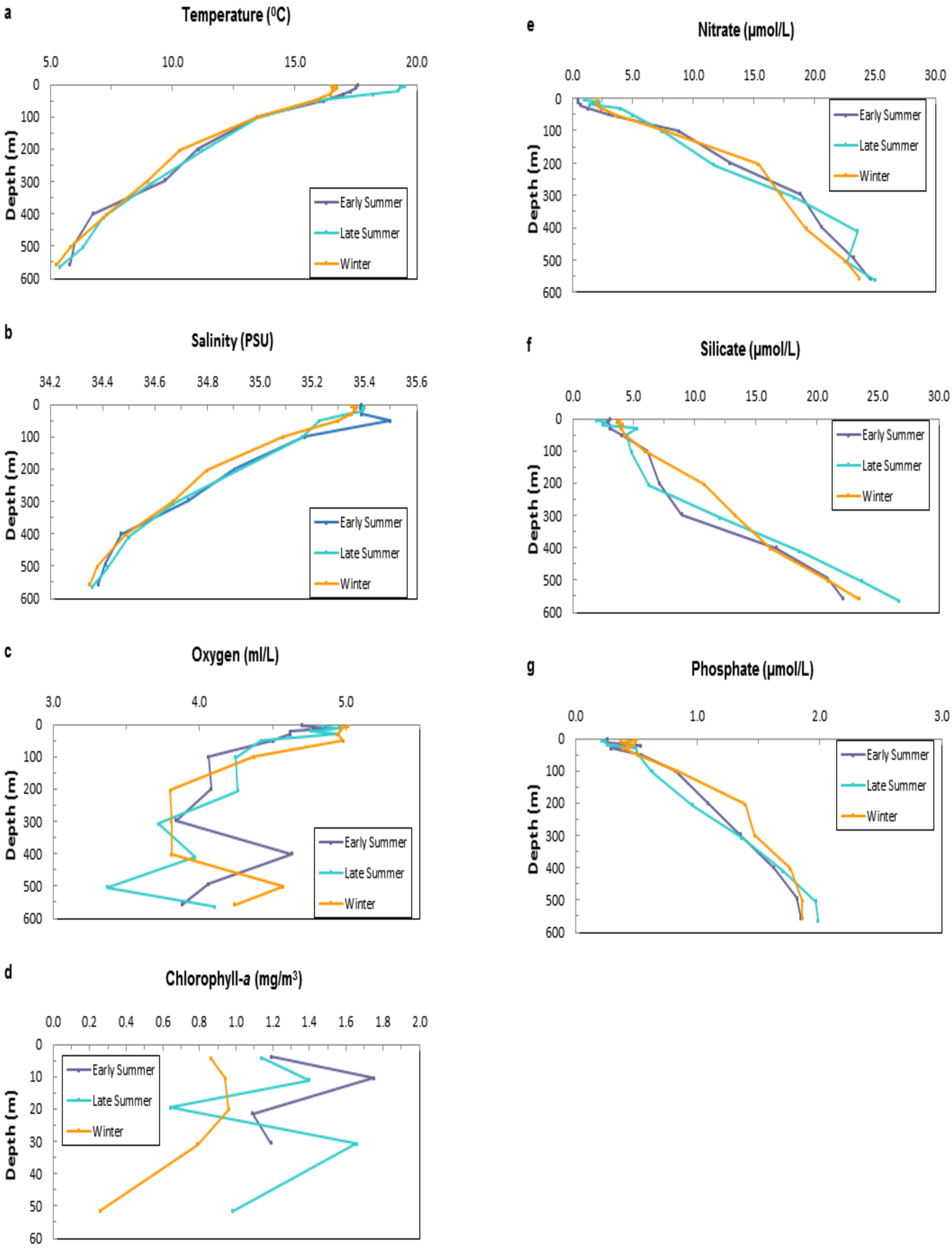


Figure 17 Station 11 vertical distribution of (a) temperature (°C), (b) salinity (PSU), (c) oxygen (ml/L), (e) nitrate (µmol/L), (f) silicate (µmol/L), (g) phosphate (µmol/L) to 600 m and (d) Chl-a (mg/m^3) to 60 m.

4.3 Linear Lagged Correlations

Table 3 suggests that the average interval between upwelling driven southerly wind events varies over a fairly small range, 7.7 days in July to 8.6 days in March. The table further indicates that wind speed reaches a maximum in January and that, on average, northerly winds, i.e. downwelling conditions only occur during the months May to August (as seen in the negative wind speed minima). A simple estimation of the vertical velocity due to Ekman upwelling at Cape Columbine (latitude 32.83°S, and using a wind speed of 7.7 m/s, a water depth of 200 m, air density = 1.22 kg.m^{-3}, a drag coefficient, $C_d = 1.14 \times 10^{-3}$, and the Brunt-Väisälä frequency, $N = 3 \times 10^{-3}\ s^{-1}$) gives a vertical velocity of 11.9 m/day.

In other words, assuming a state of rest and a constant southerly wind of 7.7 m/s, it is to be expected that it will take 2 to 5 days for water from below the thermocline (typically 20 to 50 m deep) to outcrop on the surface. However, a state of rest will only exist after a period of quiescent upwelling, towards the end of winter (August) or early summer (December). With strengthening of southerly winds and an average period of 8 days between events, the thermocline depth is expected to decrease and so also the lag between a wind event and the time that the effect of the upwelling is detectable in the SHBML surface samples. It is therefore anticipated that the lag, at which the best correlation occurs, will change with season.

Taking the small peninsula of Cape Columbine as the origin of the upwelling plume, then the approximate lengths of the trajectories of the upwelled water to the outer SHBML stations, 7 and 10 are 40 km and 84 km respectively, and to the inner stations 2 and 5, are 86 and 40 km respectively. The trajectories to the outer stations were taken as straight lines and to the inner stations as curves into the bay. The distances are therefore quite similar, but while the outer stations are probably directly in the path of the advecting water, the inshore stations are significantly towards the east of the presumed advection path. It is therefore expected that the effect of upwelling might be felt later at the inner stations than at the outer ones.

When considering the effect of upwelling on the surface parameters, it must be borne in mind that the wind driving upwelling will also generate surface turbulence which in itself may affect the water properties. This is particularly so in the case of dissolved oxygen where upwelling will bring oxygen-poor water to the surface, while the wind-generated turbulence will tend to enhance the absorption of atmospheric oxygen and therefore work in opposition to upwelling. Because surface turbulence is much more rapid than upwelling, one expects that with the onset of a wind event, surface dissolved oxygen concentration may initially increase but later decrease as sub-surface water is brought to the surface by upwelling. The enhanced surface evaporation will also tend to decrease surface temperature and increase surface salinity, but it is expected that in both cases the effect will be small.

It must also be borne in mind that while upwelling will bring about nutrient enrichment of surface waters, this enrichment might trigger a phytoplankton bloom resulting in increased levels of Chl-*a* concentration and reduced nutrient concentration. This relationship is further complicated by the fact that, in many instances, phytoplankton primary production is restrained by low water temperatures so that blooms tend to occur only after the upwelled water has been warmed up by insolation at the surface. Therefore, several interesting observations arise from this dataset.

4.3.1 Lagged Inshore and Offshore data on sea surface temperature

As expected the six sets of lagged correlations (two sets of stations in three seasons) produced predominantly negative relationships. A significant (97%) positive relationship was only obtained from the inshore stations in late summer (**Table 7**, January to March) at a lag of 7 days. There is no obvious physical explanation for this result. In four of the six sets, highly significant (97 to 98%) negative relationships were obtained at lags of 0 to 4 days. The corresponding correlation coefficients (R) were however fairly low, 0.5 to 0.7, suggesting a high degree of scatter.

In winter (**Table 8**, June to August) and early summer (**Table 6**, December), significant (≥ 90%) negative relationships occurred at both short lags (0 to 4 days) as well as long lags (8 to 10 days). In late summer (**Table 7**, February), a significant negative relationship was only found with the offshore stations and then only at short lags (1 to 2 days). To a degree, this pattern seems to fit a combination of surface turbulent cooling (at a lag of 0 to 4 days) and cooling through upwelling which occurs after a lag of 8 to 10 days in winter (**Table 8**, June to August) and early summer (**Table 6**, December), but at a lag of less than 4 days in late summer (**Table 7**, February). In other words, in late summer (**Table 7**, February), the upwelling response is rapid, and its cooling effect cannot be distinguishable from surface turbulent cooling.

It follows that if, during winter (**Table 8**, June to August) and early summer (**Table 6**, December), the effect of upwelling is only detectable as surface cooling after a lag of 8 to 10 days, then the maximum lag used during these experiments is too short to test the hypothesis that upwelled water takes longer to reach the inshore stations. Conversely, it should be possible to detect such an effect during late summer (**Table 7**, February) when the upwelling response appears to be in the order of 0 to 4 days, but there is no evidence of this in the results. The only significant correlation obtained with the inshore stations during late summer (**Table 7**, February) is the inexplicable positive correlation at a lag of 7 days.

4.3.2 Lagged Inshore and Offshore Data on Sea Surface Salinity

Significant correlations (≥ 90%) were obtained with five out of the six data sets and all of them were negative relationships as one would expect from upwelling. In these instances the correlation coefficients (R) ranged between 0.4 and 0.8, similar to what was obtained with temperature. Significances ranged between 93% and 99%. The set which did not produce a significant relationship are the offshore stations during late summer (**Table 7**, February). In this case the best correlation is only significant at 88%.

As was the case with temperature, the best correlations tended to cluster at short lags (1 to 4 days) and long lags (7 to 10 days) with those at long lags being the best. In early summer (**Table 6**, December), particularly strong negative relationships, several with significances of 98 and 99% were obtained at lags of 7 to 10 days. And this supports the tentative conclusion drawn from the temperature results that during this season the influence of upwelling is only felt after a lag of 7 to 10 days. However, the rest of the salinity results fit in poorly with the temperature results. For instance, during the winter (**Table 8**, June to August) when the best correlations were also expected at long lags, the relationships were actually very weak (significance ≤ 85%); instead, the best relationships (significance 93 to 96%) occurred at a lag of 4 days. Also, during late summer (**Table 7**, February) when strong relationships were expected at short lags, the best one occurred at a lag of 4 days and was significant at only 88%, while a good correlation (98%) occurred at a lag of 10 days.

4.3.3 Lagged Inshore and Offshore Data on Dissolved Oxygen

It was postulated that surface dissolved oxygen concentrations would be reduced by subsurface water being upwelled to the surface but increased perhaps at shorter lags through wind-induced surface turbulence. The results obtained from the lagged correlations, however do not support this hypothesis. In the first place, relatively few significant correlations were obtained (7) of which only three were negative. Correlation coefficients (R) and significances were also somewhat weaker than was the case with the other parameters (0.4 to 0.6 and 91 to 98%). The negative correlations presumed to be the direct consequence of upwelling, occurred at lags of 4 and 0 days in winter (**Table 8**, June to August) and early summer (**Table 6**, December) respectively, and at a lag of 10 days in late summer (**Table 7**, February). All four significant positive correlations occurred at lags between 3 and 6 days. In other words, virtually none of the oxygen results fit the expected pattern.

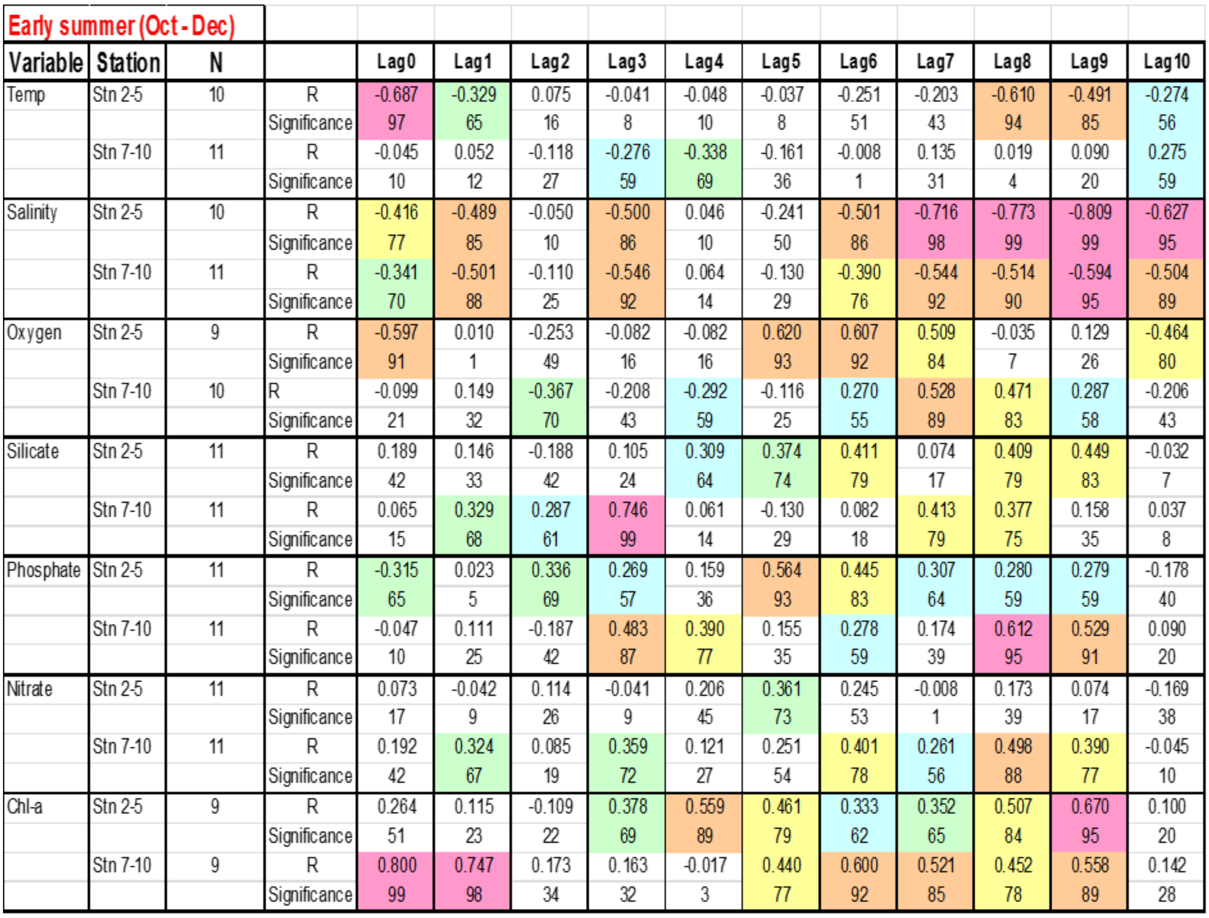
4.3.4 Lagged Inshore and Offshore Data on Surface Nutrients

All three nutrients produced significant positive and negative relationships, but positive relationships dominated at a ratio of 18:8. The positive correlation coefficients and their significances were also slightly better than the negative ones (0.4 to 0.8 and 0.4 to 0.7, 96% and 94% respectively). Significant negative correlations occurred mainly during late summer (**Table 7**, February) and then at lags of 7 to 9 days. Also, in this season, significant positive correlations between south-north wind and nutrients only occurred at short lags (0 to 2 days), an observation which supports the earlier temperature-based conclusion that the influence of upwelling develops most rapidly at this time of the year. Possibly, the negative correlations of 7 to 9 days later are caused by planktonic depletion of nutrients. During winter (**Table 8**, June to August) and early summer (**Table 6**, December) significant positive correlations were clustered at both short lags (0 to 5 days) and long lags (8 to 10 days).

4.3.5 Lagged Inshore and Offshore Data on Surface Chlorophyll-a

Relatively few (8) significant correlations were obtained with surface Chl-*a* data, and these were all positive relationships with correlation coefficients (R) ranging between 0.4 and 0.8, and significant at levels ranging between 92 and 99%. As was the case with nutrient relationships, high correlations in late summer (**Table 6**, February) only occurred at short lags (0 to 2 days), but in the other two seasons high correlations were clustered at short lags (0 to 4 days) as well as long lags (6 to 10 days), suggesting a rapid increase in Chl-*a* levels following nutrient enrichment of the surface layers.

Table 6 Lagged correlations (0 to 10 days) performed on the inshore (2 to 5) and offshore (7 to 10) stations in early summer for each of the seven oceanographic parameters. N = number of data records and R = correlation coefficient.



Early summer (Oct - Dec)

Variable	Station	N		Lag0	Lag1	Lag2	Lag3	Lag4	Lag5	Lag6	Lag7	Lag8	Lag9	Lag10
Temp	Stn 2-5	10	R	-0.687	-0.329	0.075	-0.041	-0.048	-0.037	-0.251	-0.203	-0.610	-0.491	-0.274
			Significance	97	65	16	8	10	8	51	43	94	85	56
	Stn 7-10	11	R	-0.045	0.052	-0.118	-0.276	-0.338	-0.161	-0.008	0.135	0.019	0.090	0.275
			Significance	10	12	27	59	69	36	1	31	4	20	59
Salinity	Stn 2-5	10	R	-0.416	-0.489	-0.050	-0.500	0.046	-0.241	-0.501	-0.716	-0.773	-0.809	-0.627
			Significance	77	85	10	86	10	50	86	98	99	99	95
	Stn 7-10	11	R	-0.341	-0.501	-0.110	-0.546	0.064	-0.130	-0.390	-0.544	-0.514	-0.594	-0.504
			Significance	70	88	25	92	14	29	76	92	90	95	89
Oxygen	Stn 2-5	9	R	-0.597	0.010	-0.253	-0.082	-0.082	0.620	0.607	0.509	-0.035	0.129	-0.464
			Significance	91	1	49	16	16	93	92	84	7	26	80
	Stn 7-10	10	R	-0.099	0.149	-0.367	-0.208	-0.292	-0.116	0.270	0.528	0.471	0.287	-0.206
			Significance	21	32	70	43	59	25	55	89	83	58	43
Silicate	Stn 2-5	11	R	0.189	0.146	-0.188	0.105	0.309	0.374	0.411	0.074	0.409	0.449	-0.032
			Significance	42	33	42	24	64	74	79	17	79	83	7
	Stn 7-10	11	R	0.065	0.329	0.287	0.746	0.061	-0.130	0.082	0.413	0.377	0.158	0.037
			Significance	15	68	61	99	14	29	18	79	75	35	8
Phosphate	Stn 2-5	11	R	-0.315	0.023	0.336	0.269	0.159	0.564	0.445	0.307	0.280	0.279	-0.178
			Significance	65	5	69	57	36	93	83	64	59	59	40
	Stn 7-10	11	R	-0.047	0.111	-0.187	0.483	0.390	0.155	0.278	0.174	0.612	0.529	0.090
			Significance	10	25	42	87	77	35	59	39	95	91	20
Nitrate	Stn 2-5	11	R	0.073	-0.042	0.114	-0.041	0.206	0.361	0.245	-0.008	0.173	0.074	-0.169
			Significance	17	9	26	9	45	73	53	1	39	17	38
	Stn 7-10	11	R	0.192	0.324	0.085	0.359	0.121	0.251	0.401	0.261	0.498	0.390	-0.045
			Significance	42	67	19	72	27	54	78	56	88	77	10
Chl-a	Stn 2-5	9	R	0.264	0.115	-0.109	0.378	0.559	0.461	0.333	0.352	0.507	0.670	0.100
			Significance	51	23	22	69	89	79	62	65	84	95	20
	Stn 7-10	9	R	0.800	0.747	0.173	0.163	-0.017	0.440	0.600	0.521	0.452	0.558	0.142
			Significance	99	98	34	32	3	77	92	85	78	89	28

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85-94	🟧
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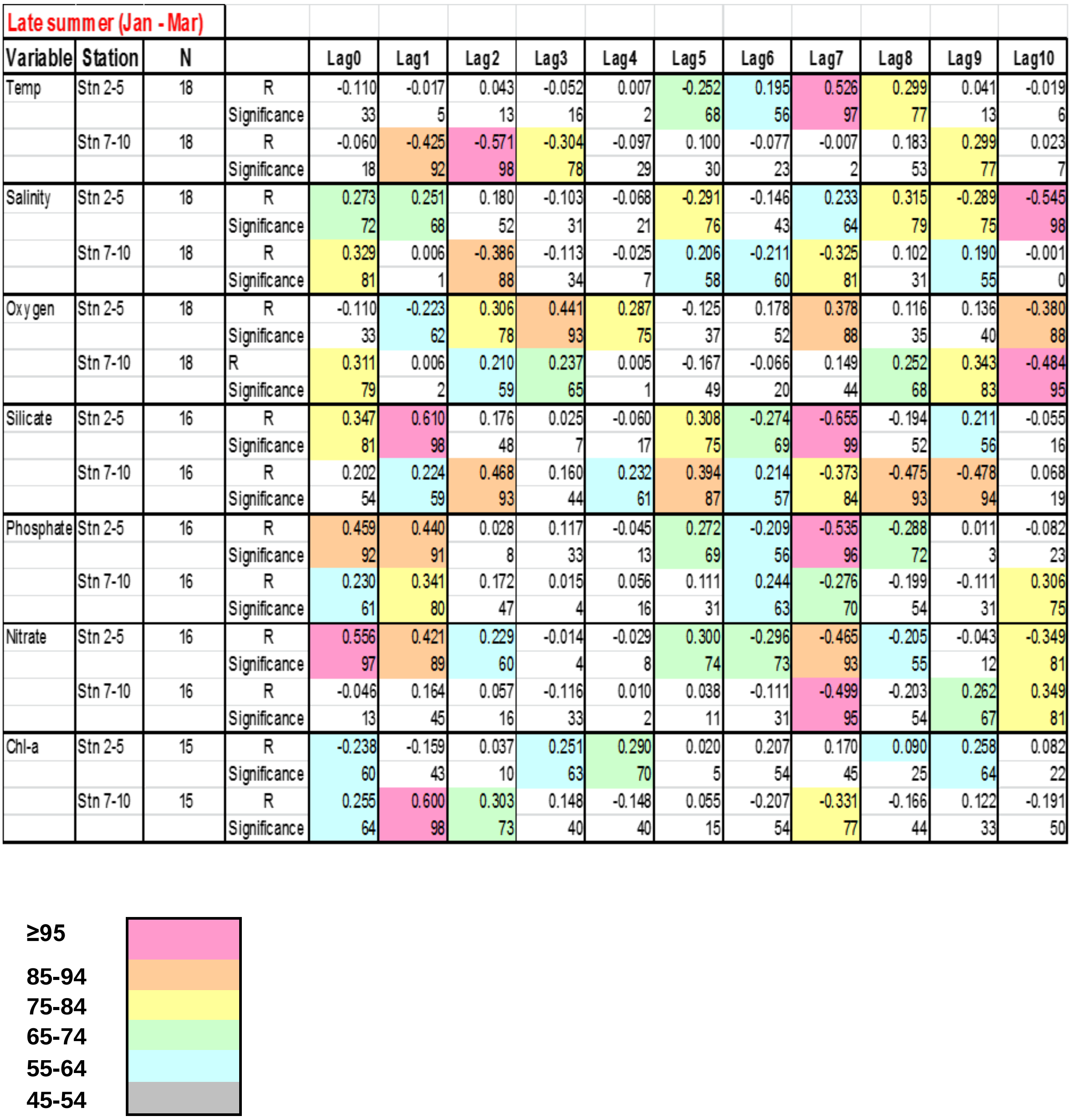
65-74	🟩
55-64	🟦
45-54	⬜

Table 7 Lagged correlations (0 to 10 days) performed on the inshore (2 to 5) and offshore (7 to 10) stations in late summer for each of the seven oceanographic parameters. N = number of data records and R = correlation coefficient.



Late summer (Jan - Mar)

Variable	Station	N		Lag0	Lag1	Lag2	Lag3	Lag4	Lag5	Lag6	Lag7	Lag8	Lag9	Lag10
Temp	Stn 2-5	18	R	-0.110	-0.017	0.043	-0.052	0.007	-0.252	0.195	0.526	0.299	0.041	-0.019
			Significance	33	5	13	16	2	68	56	97	77	13	6
	Stn 7-10	18	R	-0.060	-0.425	-0.571	-0.304	-0.097	0.100	-0.077	-0.007	0.183	0.299	0.023
			Significance	18	92	98	78	29	30	23	2	53	77	7
Salinity	Stn 2-5	18	R	0.273	0.251	0.180	-0.103	-0.068	-0.291	-0.146	0.233	0.315	-0.289	-0.545
			Significance	72	68	52	31	21	76	43	64	79	75	98
	Stn 7-10	18	R	0.329	0.006	-0.386	-0.113	-0.025	0.206	-0.211	-0.325	0.102	0.190	-0.001
			Significance	81	1	88	34	7	58	60	81	31	55	0
Oxygen	Stn 2-5	18	R	-0.110	-0.223	0.306	0.441	0.287	-0.125	0.178	0.378	0.116	0.136	-0.380
			Significance	33	62	78	93	75	37	52	88	35	40	88
	Stn 7-10	18	R	0.311	0.006	0.210	0.237	0.005	-0.167	-0.066	0.149	0.252	0.343	-0.484
			Significance	79	2	59	65	1	49	20	44	68	83	95
Silicate	Stn 2-5	16	R	0.347	0.610	0.176	0.025	-0.060	0.308	-0.274	-0.655	-0.194	0.211	-0.055
			Significance	81	98	48	7	17	75	69	99	52	56	16
	Stn 7-10	16	R	0.202	0.224	0.468	0.160	0.232	0.394	0.214	-0.373	-0.475	-0.478	0.068
			Significance	54	59	93	44	61	87	57	84	93	94	19
Phosphate	Stn 2-5	16	R	0.459	0.440	0.028	0.117	-0.045	0.272	-0.209	-0.535	-0.288	0.011	-0.082
			Significance	92	91	8	33	13	69	56	96	72	3	23
	Stn 7-10	16	R	0.230	0.341	0.172	0.015	0.056	0.111	0.244	-0.276	-0.199	-0.111	0.306
			Significance	61	80	47	4	16	31	63	70	54	31	75
Nitrate	Stn 2-5	16	R	0.556	0.421	0.229	-0.014	-0.029	0.300	-0.296	-0.465	-0.205	-0.043	-0.349
			Significance	97	89	60	4	8	74	73	93	55	12	81
	Stn 7-10	16	R	-0.046	0.164	0.057	-0.116	0.010	0.038	-0.111	-0.499	-0.203	0.262	0.349
			Significance	13	45	16	33	2	11	31	95	54	67	81
Chl-a	Stn 2-5	15	R	-0.238	-0.159	0.037	0.251	0.290	0.020	0.207	0.170	0.090	0.258	0.082
			Significance	60	43	10	63	70	5	54	45	25	64	22
	Stn 7-10	15	R	0.255	0.600	0.303	0.148	-0.148	0.055	-0.207	-0.331	-0.166	0.122	-0.191
			Significance	64	98	73	40	40	15	54	77	44	33	50

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Table 8 Lagged correlations (0 to 10 days) performed on the inshore (2 to 5) and offshore (7 to 10) stations in winter for each of the seven oceanographic parameters. N = number of data records and R = correlation coefficient.

Winter (May - Aug)

Variable	Station	N		Lag0	Lag1	Lag2	Lag3	Lag4	Lag5	Lag6	Lag7	Lag8	Lag9	Lag10
Temp	Stn 2-5	22	R	-0.178	-0.237	-0.401	-0.393	-0.517	-0.034	0.075	-0.151	-0.046	-0.090	-0.094
			Significance	57	71	93	93	98	11	25	49	16	30	32
	Stn 7-10	22	R	0.185	0.074	-0.380	-0.372	-0.497	-0.107	0.133	-0.229	-0.095	-0.237	-0.362
			Significance	59	25	92	91	98	36	44	69	32	71	90
Salinity	Stn 2-5	21	R	-0.077	0.112	0.036	-0.045	-0.461	0.034	0.097	-0.191	-0.129	-0.152	-0.194
			Significance	26	37	12	15	96	11	32	59	42	48	60
	Stn 7-10	21	R	0.328	0.356	-0.045	-0.120	-0.410	-0.180	0.171	-0.102	-0.017	-0.184	-0.326
			Significance	85	88	15	39	93	56	54	33	5	57	85
Oxygen	Stn 2-5	22	R	0.176	-0.054	-0.328	-0.170	-0.465	0.000	0.527	0.206	0.149	0.149	0.235
			Significance	56	18	86	55	97	0	98	64	49	49	70
	Stn 7-10	22	R	0.176	-0.130	-0.164	-0.011	-0.297	-0.051	0.324	0.215	0.031	0.084	0.309
			Significance	56	43	53	3	82	17	85	66	10	29	84
Silicate	Stn 2-5	22	R	0.389	0.334	0.198	0.085	0.340	0.319	-0.241	-0.258	-0.251	0.041	0.165
			Significance	92	87	62	29	87	85	72	75	74	14	53
	Stn 7-10	22	R	0.055	0.173	0.117	0.106	0.008	0.189	0.253	0.020	-0.106	-0.104	-0.006
			Significance	19	56	39	36	2	60	74	7	36	35	2
Phosphate	Stn 2-5	22	R	0.322	0.380	0.339	0.127	0.185	0.014	-0.124	-0.004	0.159	0.008	0.194
			Significance	85	91	87	42	59	5	41	1	52	2	61
	Stn 7-10	22	R	0.071	0.075	0.255	0.391	0.727	0.499	-0.400	-0.211	-0.196	0.087	0.116
			Significance	24	25	74	92	99	98	93	65	61	29	39
Nitrate	Stn 2-5	22	R	0.518	0.505	0.340	-0.069	0.160	-0.019	-0.136	-0.296	-0.076	0.041	0.449
			Significance	98	98	87	24	52	6	45	81	26	14	96
	Stn 7-10	22	R	-0.384	-0.188	0.088	0.267	0.512	0.263	-0.264	-0.174	-0.239	-0.108	-0.196
			Significance	92	59	30	77	98	76	76	56	71	36	61
Chl-a	Stn 2-5	19	R	0.625	0.377	-0.378	-0.351	-0.359	0.040	0.380	0.108	0.354	0.429	0.544
			Significance	99	89	89	86	87	12	89	34	86	93	98
	Stn 7-10	18	R	-0.042	-0.244	-0.108	-0.139	-0.337	-0.118	0.085	-0.049	0.018	0.012	0.369
			Significance	13	67	32	41	83	36	26	15	5	3	87

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85-94	🟧
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65-74	🟩
55-64	🟦
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Chapter 5

Highlights, Conclusions and Recommendations

It is clear from the results that all the physical and chemical parameters exhibit pronounced across-shelf variability along the SHBML in the surface ocean, but very poor seasonality and no significant relationship with the calculated upwelling index. This does not mean that the observed weak relationships do not provide valuable insight into upwelling processes in SHB. It does mean, however, that the weak relationship between wind-induced upwelling and inner shelf temperature cast doubt on the usefulness of satellite observations in detecting upwelling events in this part of the southern BUS, as reflected either in decreased SST or in surface Chl-*a* distributions. It also poses a problem for using moored offshore buoys as detectors of upwelling events. The tabulated regression coefficients for the UI and temperature suggest that station 2 (located approximately 7 km offshore) would be the best location to moor such a buoy and that the focus should be on temperature variability at 20 m depth rather than at the surface.

The observation that surface heating and water column stratification resulting from it outbalance wind-induced vertical mixing during the upwelling season in SHB has important implications. First of all, it explains the poor correlation between sea surface temperature variability and the upwelling index, as well as the poor correlation between the UI and nutrient parameters. Secondly, it implies that remote sensing techniques will be poor indicators of upwelling related variability in surface temperature and chlorophyll-*a* distributions in SHB. It is also a critical observation in regard to understanding the factors that contribute to harmful algal blooms and the increasing incidence of such events.

A significant (97%) positive relationship for SST was only obtained from the inshore stations in late summer at a lag of 7 days, but there is no obvious physical explanation for this result. In four of the six sets, highly significant (97 to 98%) negative relationships were obtained at lags of 0 to 4 days. The corresponding R values were however fairly low (0.5 to 0.7), suggesting a high degree of scatter. In winter and early summer, significant (≥ 90%) negative relationships occurred at both short lags (0 to 4 days) as well as long lags (8 to 10 days) whereas in late summer, a significant negative relationship was only found with the offshore stations and then only at short lags (1 to 2 days). To a degree, this pattern seems to fit a combination of surface turbulent cooling through upwelling which occurs after a lag of 8 to 10 days in winter and early summer, but at a lag of less than 4 days in late summer. In other words, in late summer, the upwelling response is rapid, and its cooling effect cannot be distinguishable from surface turbulent cooling. It follows that if, during winter and early summer, the effect of upwelling is only detectable as surface cooling after a lag of 8 to 10 days, then the maximum lag used during these experiments is too short to test the hypothesis that upwelled water takes longer to reach the inshore stations. Conversely, it should be possible to detect such an effect during late summer when the upwelling response appears to be in the order of 0 to 4 days, but there is no evidence of this in the results. The only significant correlation obtained with the inshore stations during late summer is the inexplicable positive correlation at a lag of 7 days.

Significant (≥ 90%) negative correlations for salinity were obtained in five out of the six data sets as one would expect from upwelling. In these instances, R ranged between 0.4 and 0.8, similar to what was obtained with temperature. Significances ranged between 93% and 99%. The set which did not produce a significant relationship was the offshore stations during late summer, the best correlation being significant at 88%. As was the case with temperature, the best correlations tended to cluster at short lags (1 to 4 days) and long lags (7 to 10 days) with those at long lags being the best. In early summer, particularly strong negative relationships, with significances of 98 and 99% were obtained at lags of 7 to 10 days and this supports the tentative conclusion drawn from the temperature results that during this season the influence of upwelling is only felt after a lag of 7 to 10 days. However, the rest of the salinity results fit in poorly with the temperature results. For instance, during the winter when the best correlations were also expected at long lags, the relationships were actually very weak; instead, the best relationships occurred at a lag of 4 days. Also, during late summer when strong relationships were expected at short lags, the best one occurred at a lag of 4 days and was significant at only 88%, while a good correlation (98%) occurred at a lag of 10 days.

The results obtained from the lagged correlations for surface dissolved oxygen concentration reductions, however, do not support the hypothesis that the subsurface water is being upwelled to the surface but increases perhaps at shorter lags through wind-induced surface turbulence. R and significances were also somewhat weaker than was the case with the other parameters (0.4 to 0.6 and 91 to 98%). In other words, for all three seasons virtually none of the oxygen results fit the expected pattern. For all three nutrients positive correlation coefficients and their significances were slightly better than the negative ones (0.4 to 0.8 and 0.4 to 0.7, 96% and 94% respectively) clustering at both short lags (0 to 5 days) and long lags (8 to 10 days). Significant negative correlations occurred mainly during late summer and at lags of 7 to 9 days caused by planktonic depletion of nutrients. Also, in this season, significant positive correlations between south-north wind and nutrients only occurred at short lags. This observation supports the earlier temperature-based conclusion that the influence of upwelling develops most rapidly at this time of the year. As was the case with nutrient relationships, high positive correlations and their significances (0.4 to 0.8 and 92 to 99%) for Chl-*a* occurred at short lags (0 to 2 days) in late summer, but in the other two seasons clustering occurred at short lags (0 to 4 days) as well as long lags (6 to 10 days), suggesting a rapid increase in Chl-

a levels following nutrient enrichment of the surface layers. These results emphasise the importance of validating lagged outputs against real-time measurements if the lagged results are to be used in a regulatory context. Significant uncertainties exist in the results found here which can be sensitive to the data used. Furthermore, in our opinion more research is needed to identify and evaluate seasonal cruises, suggesting that a probabilistic approach be implemented to motivate and support a simpler hydrological model which can be very useful in narrowing down these uncertainties (Stramma *et al.*, 2010).

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Appendices

Appendix 1

Averaged station details for 2004 to 2009 – Near surface (2-5)

Date	Temp	Salinity	Oxygen	Silicate	Phosphate	Nitrate	Chl-*a*	Upwelling
Mar-04	12.04	34.76	4.54	17.38	2.04	13.51	0.54	53.36
May-04	14.39	34.82	6.04	11.05	0.69	9.66	7.96	16.08
Jun-04	12.65	-	4.35	13.31	0.96	6.54	2.04	-22.13
Jul-04	13.32	34.86	6.14	14.05	0.65	6.12	5.62	0.79
Aug-04	12.73	34.86	5.91	8.54	0.95	5.58	5.06	-5.70
Sep-04	12.24	34.76	4.69	19.29	1.44	10.58	8.41	42.79
Oct-04	12.62	34.71	6.55	27.59	1.36	4.32	14.98	67.73
Dec-04	12.90	34.69	5.97	16.45	1.58	3.84	6.10	72.50
Jan-05	16.10	34.79	9.14	3.83	0.79	1.23	11.24	101.46
Feb-05	13.37	34.76	8.18	7.07	1.02	2.60	24.01	91.90
Mar-05	13.52	34.80	5.63	5.45	1.16	3.44	16.49	66.09
Apr-05	12.79	34.81	5.10	19.40	1.68	14.81	4.94	48.46
May-05	15.25	34.96	6.70	8.12	0.74	4.11	9.83	-16.60
Jun-05	14.37	34.87	5.01	10.19	1.39	6.77	2.07	-9.58
Jul-05	14.01	34.95	4.05	5.98	0.74	4.18	3.02	1.11
Aug-05	14.53	35.06	5.02	7.69	0.80	4.11	4.74	-29.36
Sep-05	13.04	34.93	3.74	12.65	1.47	8.64	6.29	25.43
Oct-05	12.97	34.85	3.77	14.18	1.02	6.51	4.48	56.65
Dec-05	11.74	34.75	3.41	20.41	1.35	8.89	12.98	118.20
Jan-06	14.89	34.72	4.02	4.38	0.73	1.99	3.74	119.47
Feb-06	13.78	34.80	3.44	5.88	0.86	4.49	7.71	90.65
Mar-06	13.08	34.74	3.73	21.21	1.91	7.22	8.86	75.41
Apr-06	12.62	34.76	4.24	16.78	1.60	6.95	12.22	58.97
May-06	13.91	34.73	4.82	4.94	0.78	3.53	2.48	-2.75
Jun-06	13.55	34.83	4.51	10.55	1.17	6.64	2.71	-14.57
Aug-06	12.81	34.81	4.13	17.00	1.06	9.87	6.90	29.26
Sep-06	13.67	34.99	5.09	11.75	0.92	5.92	6.81	64.21
Oct-06	14.43	34.77	5.46	12.70	2.61	3.74	7.42	94.23
Dec-06	12.78	34.68	5.07	20.70	1.84	1.34	12.06	82.44
Jan-07	12.93	34.71	3.69	15.83	0.89	5.37	4.91	107.31
Feb-07	14.24	34.71	4.76	6.87	0.79	1.99	4.25	78.64
Mar-07	13.86	34.76	5.89	4.07	0.70	1.39	4.72	69.12
Apr-07	15.56	35.16	5.04	2.45	0.89	2.81	-	35.05
May-07	14.31	34.86	4.31	7.41	1.18	4.56	6.74	1.52
Jul-07	13.31	34.86	4.30	8.69	1.01	8.06	2.48	-6.93
Aug-07	13.06	34.74	4.45	5.70	0.86	5.70	5.09	-12.68
Sep-07	13.73	34.95	6.57	7.94	1.18	5.61	21.45	20.82
Oct-07	14.28	34.80	5.08	2.99	0.42	1.10	2.66	107.86
Dec-07	15.27	34.69	5.98	0.70	0.94	0.28	-	93.31
Jan-08	14.53	34.75	5.91	2.06	0.67	4.55	-	164.75
Feb-08	15.49	34.72	8.09	0.77	0.54	1.43	-	89.55
Mar-08	12.10	34.77	4.52	4.08	1.66	5.88	-	101.00
May-08	13.71	34.74	5.98	2.42	0.40	3.84	-	-65.64
Jun-08	14.55	34.88	5.78	3.90	0.75	6.36	-	-25.55
Jul-08	-	-	-	-	-	-	-	-64.19
Aug-08	13.78	34.85	6.90	3.18	3.85	9.74	11.57	11.85
Sep-08	14.87	34.85	6.35	8.79	4.10	9.92	5.24	-14.80
Oct-08	13.61	34.83	6.06	12.17	4.39	10.72	6.52	117.58

Nov-08	-	-	-	3.53	0.44	1.25	-	142.30
Jan-09	12.61	34.79	4.76	24.31	2.03	17.29	3.64	92.93
Feb-09	14.31	34.83	7.45	0.80	0.33	1.45	9.34	100.47
Mar-09	13.14	34.83	4.18	9.65	1.16	10.04	5.70	74.29
Apr-09	13.11	34.80	6.61	14.42	1.23	6.05	-	31.64
May-09	14.83	34.95	5.93	5.24	0.56	3.47	4.97	-26.22
Jun-09	15.01	34.97	5.99	7.02	0.48	3.93	-	-27.17
Jul-09	14.12	34.77	6.27	5.75	0.44	6.23	10.75	0.52
Aug-09	14.34	35.03	6.25	6.25	0.37	4.05	4.00	2.46
Sep-09	14.25	34.90	6.14	5.81	0.41	5.97	5.05	38.24
Dec-09	16.11	34.88	6.66	6.80	0.63	2.83	4.98	89.94

Averaged station details for 2004 to 2009 – Near surface (7-10)

Date	Temp	Salinity	Oxygen	Silicate	Phosphate	Nitrate	Chl-*a*	Upwelling
Jan-04	17.85	35.20	6.11	-	-	-	1.72	88.50
Feb-04	15.31	34.87	6.39	-	-	-	7.96	93.87
Mar-04	17.29	35.22	5.95	3.78	0.44	4.07	5.11	53.36
Apr-04	16.62	35.20	5.37	-	-	-	0.43	7.29
May-04	16.57	35.17	5.58	6.11	0.16	2.34	4.51	16.08
Jun-04	15.30	-	5.59	1.29	0.22	6.02	1.32	-22.13
Jul-04	15.50	35.22	5.61	5.13	0.76	6.46	1.34	0.79
Aug-04	15.64	35.26	6.01	1.03	0.24	4.57	1.75	-5.70
Sep-04	15.19	35.10	5.89	0.99	0.52	3.46	2.67	42.79
Oct-04	15.48	35.12	5.70	0.47	0.40	4.77	4.07	67.73
Dec-04	17.88	35.16	6.33	0.16	0.40	3.22	4.04	72.50
Jan-05	15.87	35.04	8.23	2.85	0.69	2.53	4.68	101.46
Feb-05	16.32	34.93	7.43	0.88	0.48	1.75	4.85	91.90
Mar-05	15.38	35.03	6.06	2.03	0.64	2.47	4.03	66.09
Apr-05	15.89	34.96	8.28	3.02	0.67	5.19	5.27	48.46
May-05	18.70	35.39	5.25	1.25	0.51	4.91	0.77	-16.60
Jun-05	16.54	35.21	5.09	1.99	0.88	5.69	0.91	-9.58
Jul-05	16.52	35.31	3.77	1.47	0.35	4.31	0.87	1.11
Aug-05	15.95	35.38	4.47	2.01	0.43	5.96	0.61	-29.36
Sep-05	15.54	35.32	4.43	1.33	0.54	5.18	0.74	25.43
Oct-05	16.28	35.34	4.18	0.00	0.29	2.88	0.61	56.65
Dec-05	15.80	35.21	3.46	0.66	0.33	3.80	5.75	118.20
Jan-06	17.90	35.08	4.07	0.03	0.27	2.51	0.85	119.47
Feb-06	16.65	34.89	3.27	0.66	0.44	2.43	1.77	90.65
Mar-06	16.29	35.09	3.80	2.14	0.64	3.40	4.64	75.41
May-06	15.37	35.15	4.44	4.14	0.68	6.03	0.99	-2.75
Jun-06	14.20	35.04	4.59	3.38	1.06	7.61	2.46	-14.57
Aug-06	14.30	35.13	4.53	3.79	1.52	5.12	0.90	29.26
Oct-06	15.75	35.18	5.07	2.13	0.64	4.58	0.50	94.23
Dec-06	15.91	35.05	4.94	0.86	0.34	5.03	3.86	82.44
Jan-07	15.26	34.99	4.02	4.31	0.47	7.68	1.20	107.31
Feb-07	18.77	35.09	6.03	0.55	0.49	4.26	8.51	78.64
Mar-07	17.07	34.97	4.68	0.99	0.42	6.94	1.69	69.12
Apr-07	18.38	35.36	4.03	1.30	0.38	2.22	-	35.05
May-07	16.52	35.28	4.27	3.13	1.71	5.21	-	1.52
Jul-07	15.35	35.17	4.25	4.75	0.70	7.16	1.53	-6.93
Aug-07	15.70	35.26	4.18	3.45	0.88	6.26	1.02	-12.68
Sep-07	17.29	35.42	6.26	0.27	0.51	0.04	2.88	20.82

Oct-07	16.29	35.18	4.56	1.00	0.03	2.66		107.86
Dec-07	17.41	35.11	3.94	0.11	0.05	0.33	1.69	93.31
Jan-08	15.25	34.88	4.67	7.28	0.67	2.90		164.75
Feb-08	17.44	34.80	6.63	0.12	0.41	1.90	-	89.55
Mar-08	16.17	35.06	4.68	1.82	0.48	0.37	-	101.00
May-08	14.95	35.01	5.70	3.66	0.82	5.07	-	-65.64
Jun-08	17.71	35.34	5.46	-	-	-	-	-25.55
Aug-08	16.11	35.38	5.73	2.22	0.17	1.03	1.54	11.85
Sep-08	15.99	35.43	5.69	-	-	-	0.83	-14.80
Oct-08	16.85	35.38	5.85	0.25	0.23	3.24	2.51	117.58
Nov-08	16.96	35.24	6.59	1.10	0.18	2.33	-	142.30
Jan-09	16.48	35.16	5.68	2.44	0.29	3.32	4.61	92.93
Feb-09	17.25	35.09	6.08	1.00	0.18	1.26	2.51	100.47
Mar-09	15.47	34.94	5.81	4.80	0.74	1.71	4.48	74.29
Apr-09	16.64	35.15	5.86	3.62	0.48	2.18	-	31.64
Jun-09	15.98	35.27	5.59	2.49	0.09	5.01	-	-27.17
Jul-09	15.51	35.21	6.32	1.34	0.18	2.05	3.86	0.52
Aug-09	16.15	35.38	5.63	1.85	0.36	3.90	0.75	2.46
Sep-09	16.85	35.44	5.64	1.89	0.29	3.37	0.79	38.24
Oct-09	16.69	35.42	-	0.31	0.07	1.48	1.61	78.90
Dec-09	17.33	35.15	5.79	0.48	0.38	2.76	1.60	89.94

Station details for station 1 – Near surface

Date	Temp	Salinity	Oxygen	Silicate	Phosphate	Nitrate	Chl-*a*	Upwelling
Mar-04	10.32	34.76	1.49	39.02	2.88	23.88	1.22	53.36
May-04	13.75	34.76	6.59	12.27	1.16	8.76	13.33	16.08
Jun-04	11.65	-	4.14	17.45	1.13	6.61	0.82	-22.13
Jul-04	12.68	34.79	6.72	13.34	0.40	8.00	8.97	0.79
Aug-04	12.20	34.78	5.97	5.65	0.66	7.89	4.13	-5.70
Sep-04	13.48	34.79	7.02	6.04	0.74	1.55	12.73	42.79
Oct-04	11.58	34.72	4.59	41.18	2.34	12.98	9.57	67.73
Dec-04	9.80	34.70	1.17	33.28	2.43	18.89	-	72.50
Jan-05	17.38	34.79	8.40	6.47	0.82	0.17	33.40	101.46
Feb-05	11.55	34.75	3.83	25.32	2.36	9.95	27.26	91.90
Mar-05	12.04	34.82	2.66	14.77	2.39	12.63	4.83	66.09
Apr-05	12.28	34.82	3.46	23.20	3.95	12.65	3.92	48.46
May-05	14.71	34.85	8.58	4.93	0.99	2.86	41.11	-16.60
Jun-05	13.92	34.81	4.75	13.02	1.79	8.95	1.25	-9.58
Jul-05	13.35	34.86	3.87	9.63	1.17	8.63	1.34	1.11
Aug-05	14.25	34.88	4.96	9.46	1.19	6.75	6.34	-29.36
Sep-05	10.29	34.78	0.83	33.84	4.16	26.53	3.86	25.43
Oct-05	11.49	34.77	2.54	27.32	1.71	14.28	3.20	56.65
Dec-05	10.85	34.72	2.31	32.23	2.44	17.78	2.85	118.20
Jan-06	11.21	34.74	2.81	21.84	2.02	16.54	4.19	119.47
Feb-06	13.86	34.82	4.32	6.18	0.61	1.11	9.78	90.65
Mar-06	11.25	34.77	2.07	38.34	2.92	18.53	3.47	75.41
May-06	13.12	34.75	6.43	13.79	1.24	0.46	13.17	-2.75
Jun-06	13.11	34.83	4.23	13.44	1.38	9.59	3.09	-14.57

Aug-06	11.47	34.84	2.00	46.76	1.81	20.21	1.51	29.26
Sep-06	12.04	34.82	2.76	40.24	1.58	13.38	3.76	64.21
Oct-06	14.93	34.76	4.79	16.63	1.60	8.53	8.54	94.23
Dec-06	10.59	34.68	2.97	31.53	2.20	14.55	8.49	82.44
Jan-07	10.66	34.68	1.67	36.21	1.97	15.40	9.22	107.31
Feb-07	11.80	34.75	2.34	-	-	-	11.87	78.64
Mar-07	13.20	34.77	5.32	5.43	0.70	2.46	15.63	69.12
Apr-07	14.62	34.76	5.59	6.33	1.05	4.64	-	35.05
May-07	13.54	34.80	3.04	20.44	2.09	9.89	0.94	1.52
Jul-07	12.95	34.74	4.11	11.33	0.98	9.74	1.17	-6.93
Aug-07	13.16	34.41	4.67	5.42	1.19	7.09	5.63	-12.68
Sep-07	11.24	34.80	2.96	27.67	2.48	19.49	10.92	20.82
Oct-07	14.56	34.75	5.17	1.17	0.26	0.68	-	107.86
Dec-07	15.78	34.70	6.05	0.29	1.21	0.73	-	93.31
Jan-08	13.96	34.74	5.10	0.81	0.67	2.87	-	164.75
Feb-08	15.93	34.71	6.93	1.64	0.99	1.12	-	89.55
Mar-08	11.04	34.76	3.05	14.52	2.81	13.14	-	101.00
May-08	13.57	34.78	5.98	5.62	0.67	3.15	-	-65.64
Aug-08	13.27	34.71	6.44	9.85	1.02	5.55	9.83	11.85
Sep-08	14.72	34.59	5.55	11.11	0.94	6.49	2.68	-14.80
Oct-08	12.67	34.85	2.38	-	-	-	-	117.58
Nov-08	12.99	34.75	5.77	15.07	1.26	10.40	8.40	142.30
Jan-09	12.02	34.75	3.72	40.23	2.40	24.56	2.65	92.93
Feb-09	13.47	34.80	8.09	-	-	-	17.61	100.47
Mar-09	10.56	34.83	1.54	23.93	2.13	23.98	6.78	74.29
Apr-09	12.09	34.80	6.01	-	-	-	-	31.64
Jun-09	14.72	34.89	5.36	9.62	0.69	5.71	-	-27.17
Jul-09	14.11	34.67	5.95	6.86	0.54	6.43	10.99	0.52
Aug-09	13.37	34.92	4.75	17.08	0.86	12.69	1.00	2.46
Sep-09	12.92	34.86	4.45	18.59	1.16	17.30	3.85	38.24
Dec-09	15.26	34.89	-	7.24	0.66	2.41	2.18	78.90

Station details - 20m

Station	Date	Upwelling	Temp	Salinity	Oxygen	Nitrate	Silicate	Phosphate	Chl-*a*
1	13/01/2004	88.50	10.26	34.71	1.36	-	-	-	6.26
2	13/01/2004	88.50	9.51	34.72	0.08	-	-	-	3.26
3	13/01/2004	88.50	11.65	34.70	3.21	-	-	-	1.05
4	13/01/2004	88.50	12.16	34.71	4.5	-	-	-	3.29
5	13/01/2004	88.50	11.41	34.84	4.6	-	-	-	4.52
6	13/01/2004	88.50	15.98	34.97	5.83	-	-	-	3.73
7	13/01/2004	88.50	14.93	34.97	5.62	-	-	-	4.05
8	13/01/2004	88.50	15.81	35.02	5.84	-	-	-	3.71
9	13/01/2004	88.50	16.86	35.30	6.26	-	-	-	3.5
10	13/01/2004	88.50	18.86	35.46	5.85	-	-	-	1.09
11	13/01/2004	88.50	19.9	35.58	5.23	-	-	-	0.11

12	13/01/2004	88.50	19.98	35.57	5.13	-	-	-	0.11
1	21/02/2004	93.87	10.02	34.77	1.3	-	-	-	1.64
2	21/02/2004	93.87	9.88	34.76	1.32	-	-	-	6.94
3	20/02/2004	93.87	9.77	34.76	2.08	-	-	-	1.53
4	20/02/2004	93.87	10.32	34.75	2.11	-	-	-	1.35
5	20/02/2004	93.87	9.68	34.74	1.21	-	-	-	0.67
6	20/02/2004	93.87	12.59	34.88	4.25	-	-	-	5.84
7	20/02/2004	93.87	13.57	34.88	5.2	-	-	-	7.81
8	20/02/2004	93.87	14.32	34.86	5.46	-	-	-	7.57
9	20/02/2004	93.87	15.38	34.93	5.48	-	-	-	3.68
10	20/02/2004	93.87	15.59	34.93	5.92	-	-	-	6.31
11	20/02/2004	93.87	16.93	35.12	5.7	-	-	-	2.43
12	20/02/2004	93.87	18.47	35.38	5.43	-	-	-	2.05
1	06/03/2004	53.36	9.79	34.76	1.02	29.66	34.1	2.6	1.18
2	06/03/2004	53.36	9.79	34.76	1.04	30.7	34.69	2.65	0
3	06/03/2004	53.36	9.98	34.76	1.85	-	-	-	7.59
4	06/03/2004	53.36	10.61	34.75	2.84	-	-	-	4.18
5	06/03/2004	53.36	11.56	34.79	4.73	-	-	-	8.37
6	06/03/2004	53.36	12.85	34.76	5.29	-	-	-	8.11
7	06/03/2004	53.36	13.32	34.76	6.43	-	-	-	11.68
8	06/03/2004	53.36	14.78	35.09	5.87	-	-	-	7.62
9	07/03/2004	53.36	19.5	35.46	5.03	-	-	-	0.9
10	07/03/2004	53.36	20.05	35.51	4.95	-	-	-	1.04
11	07/03/2004	53.36	20.57	35.55	5.11	-	-	-	0.38
12	07/03/2004	53.36	20.61	35.56	5.06	-	-	-	0.45
1	27/04/2004	7.29	9.96	34.75	-	-	-	-	2.43
2	27/04/2004	7.29	9.73	34.74	-	-	-	-	1.54
3	27/04/2004	7.29	9.9	34.74	0.48	-	-	-	1.42
4	27/04/2004	7.29	12.03	34.73	3.08	-	-	-	0.72
5	27/04/2004	7.29	13.57	34.84	5.56	-	-	-	2.4
6	27/04/2004	7.29	14.19	34.99	5.29	-	-	-	0.79
7	27/04/2004	7.29	15.36	35.08	5.84	-	-	-	1.9
8	27/04/2004	7.29	15.25	35.08	5.95	-	-	-	0.29
9	27/04/2004	7.29	15.36	35.05	5.27	-	-	-	0.49
10	27/04/2004	7.29	16.97	35.25	5.55	-	-	-	0.58
11	27/04/2004	7.29	16.79	35.17	5.51	-	-	-	0.26
1	13/05/2004	16.08	11.01	34.76	3.33	-	-	-	3.69
2	13/05/2004	16.08	12.29	34.75	4.73	-	-	-	6.15
3	14/05/2004	16.08	11.73	34.76	3.43	-	-	-	0.9
4	14/05/2004	16.08	12.15	34.80	3.83	-	-	-	1.15
5	14/05/2004	16.08	13.43	34.86	4.88	-	-	-	3.01
6	14/05/2004	16.08	13.61	35.03	4.84	-	-	-	2.92
7	14/05/2004	16.08	12.87	35.00	4.62	-	-	-	0.85
8	14/05/2004	16.08	16.57	35.22	5.35	-	-	-	2.57
9	14/05/2004	16.08	17.03	35.25	5.56	-	-	-	1.42
10	14/05/2004	16.08	17.14	35.18	5.53	-	-	-	0.72

1	21/06/2004	-22.13	11.62	-	5.08	20.74	29.25	1.96	0.18
2	21/06/2004	-22.13	11.39	-	4.66	18.31	19.75	1.66	1.73
3	21/06/2004	-22.13	10.75	-	2.39	16.48	13.84	1.55	0.86
4	21/06/2004	-22.13	11.9	-	2.12	-	-	-	0.81
5	21/06/2004	-22.13	11.45	-	2.46	12.8	14.97	1.16	0.98
6	22/06/2004	-22.13	13.93	-	2.46	-	-	-	2.33
7	22/06/2004	-22.13	13.44	-	5.22	-	-	-	0.36
8	22/06/2004	-22.13	12.8	-	4.6	-	-	-	1.9
9	22/06/2004	-22.13	14.51	-	6.04	-	-	-	0.58
10	22/06/2004	-22.13	15.75	-	4.74	-	-	-	0.32
11	22/06/2004	-22.13	16.78	-	4.86	-	-	-	-
12	22/06/2004	-22.13	16.75	-	5.16	-	-	-	0.37
1	10/07/2004	0.79	11.95	34.77	4.5	13.69	21.55	1.06	4.76
2	10/07/2004	0.79	12.47	34.78	5.42	10.24	16.63	0.93	7.44
3	10/07/2004	0.79	12.53	34.78	6.64	9.33	13.09	0.99	9.47
4	10/07/2004	0.79	13.45	34.93	6.23	5.67	17.08	0.97	3.55
5	10/07/2004	0.79	13.87	34.98	5.81	3.31	10.56	0.68	2.48
6	11/07/2004	0.79	14.23	35.10	5.52	8.35	6.53	0.67	0.73
7	11/07/2004	0.79	14.02	35.08	5.56	7.01	6.29	0.81	1.31
8	11/07/2004	0.79	-	-	-	7.93	8.34	0.88	1.39
9	11/07/2004	0.79	15.13	35.17	5.71	-	-	-	1.67
10	11/07/2004	0.79	16.25	35.31	5.65	3.69	5.8	0.59	0.87
11	11/07/2004	0.79	16.68	35.35	5.54	4.19	4.48	0.39	0.55
12	11/07/2004	0.79	17.08	35.39	5.38	3.41	5	0.27	0.64
1	04/08/2004	-5.70	12.13	34.78	5.62	15.7	30.86	2.11	2.6
2	04/08/2004	-5.70	11.98	34.78	5.72	8.46	9.23	1.23	1.94
3	04/08/2004	-5.70	12.13	34.78	5.85	7.88	7.62	1.1	2.68
4	04/08/2004	-5.70	12.49	34.85	5.27	4.83	12.39	1.13	3.5
5	04/08/2004	-5.70	13.4	34.93	5.89	3.65	11.39	0.91	4.65
6	04/08/2004	-5.70	14.55	35.18	5.68	3.88	6.84	0.68	1.63
7	03/08/2004	-5.70	15.3	35.28	5.7	3.28	6.4	0.11	1.38
8	03/08/2004	-5.70	14.89	35.21	5.65	4.82	7.92	0.54	1.34
9	03/08/2004	-5.70	15.6	35.31	5.65	3.09	6.66	0.08	1.87
10	03/08/2004	-5.70	16	35.38	5.44	2.5	6.27	0.45	0.43
11	03/08/2004	-5.70	16.19	35.39	5.5	2.03	5.29	0.17	0.47
12	03/08/2004	-5.70	-	-	-	2.04	3.44	0.43	0.52
1	31/08/2004	42.79	11.1	34.77	2.37	19.15	30.14	2.21	3.94
2	31/08/2004	42.79	11.98	34.78	4.41	13.99	19.51	1.61	5.13
3	31/08/2004	42.79	12.94	34.81	5.92	4.82	5.27	0.93	9.68
4	31/08/2004	42.79	12.91	34.85	5.49	4.94	12.42	0.95	2.81
5	31/08/2004	42.79	13.51	34.71	6.93	3.21	10.83	0.54	81.72
6	31/08/2004	42.79	15.22	35.20	6.18	0.81	5.84	0.26	3.55
7	31/08/2004	42.79	15.34	35.23	5.69	1.6	4.31	0.28	1.29
8	31/08/2004	42.79	15.34	35.25	5.76	2.49	6.09	0.3	1.25
9	31/08/2004	42.79	15.53	35.27	5.95	1.25	4.63	0.3	2.4
10	31/08/2004	42.79	15.58	35.30	5.82	1.62	4.72	0.21	0.94

11	31/08/2004	42.79	16.57	35.45	5.56	2.08	2.99	0.33	0.31
12	01/09/2004	42.79	16.37	35.43	5.54	4.84	2.85	0.33	0.4
1	29/09/2004	-	9.79	34.74	1.17	24.02	39.92	2.4	0.92
2	29/09/2004	-	9.78	34.74	1.08	23.73	39.87	2.4	0.61
3	29/09/2004	-	10.08	34.74	1.9	23.38	33.84	2.35	1.96
4	29/09/2004	-	13.14	34.77	5.46	4.37	7.02	1.25	6.18
5	29/09/2004	-	11.75	34.81	4.55	12.56	14.06	1.53	10.55
6	29/09/2004	-	13.08	34.92	5.65	5.09	5.53	0.89	6.42
7	29/09/2004	-	13.83	35.00	5.51	3.79	6.24	0.7	3.44
8	29/09/2004	-	13.84	34.96	5.83	2.99	5.84	0.62	6.34
9	29/09/2004	-	16.18	35.29	5.45	0.9	2.84	0.31	1.39
10	29/09/2004	-	15.4	35.20	5.53	1.1	2.3	0.37	2.81
11	29/09/2004	-	16.92	35.40	5.19	0	1.68	0.25	0.61
12	29/09/2004	-	17.61	35.40	5.09	0.16	2.41	0.3	0.55
1	31/10/2004	67.73	9.58	34.71	0.68	23.25	45.4	2.69	1.15
2	31/10/2004	67.73	10.71	34.72	2.63	17.34	40.83	2.32	12.99
3	31/10/2004	67.73	11.58	34.72	4.76	13.52	34.17	1.8	17.16
4	31/10/2004	67.73	11.54	34.69	4.23	13.78	25.81	1.89	13.38
5	31/10/2004	67.73	12.28	34.70	5.53	8.26	13.77	1.16	12.87
6	31/10/2004	67.73	13.77	34.94	5.59	3.82	4.94	0.62	5.97
7	31/10/2004	67.73	14.26	34.98	6.13	1.44	5.13	0.25	8.75
8	31/10/2004	67.73	15.36	35.12	5.6	1.25	5.28	0.35	3.61
9	01/11/2004	67.73	15.9	35.15	5.39	0.54	5.08	0.33	3.32
10	01/11/2004	67.73	16.19	35.22	5.38	0.63	5.73	0.3	1.36
11	01/11/2004	67.73	16.98	35.35	5.42	0.6	4.79	0.4	1.13
12	01/11/2004	67.73	17.7	35.37	5.46	0.13	3.91	0.28	1.09
1	18/12/2004	72.50	9.43	34.70	0.46	25.97	40.07	2.78	-
2	18/12/2004	72.50	9.46	34.71	0.41	26.13	36.34	2.65	-
3	18/12/2004	72.50	10.24	34.71	2.39	20.82	17.65	1.96	2.01
4	18/12/2004	72.50	13.15	34.70	5.65	4.1	1.51	1.22	23.35
5	18/12/2004	72.50	11.57	34.74	4.21	14.27	13.85	1.61	1.46
6	18/12/2004	72.50	13.78	34.99	5.43	5.46	6.18	0.65	0.38
7	17/12/2004	72.50	13.66	34.89	5.33	7.06	8.82	0.76	0.54
8	17/12/2004	72.50	17.87	35.29	5.48	-	-	-	1.24
9	17/12/2004	72.50	19.77	35.37	5.36	0.31	3.53	0.17	6.42
11	17/12/2004	72.50	-	-	-	0.31	4.55	0.37	0.12
12	17/12/2004	72.50	-	-	-	0.13	2.5	0.14	0.26
1	19/01/2005	101.46	10.92	34.77	2.77	12.06	25.94	2.14	1.2
2	19/01/2005	101.46	9.94	34.76	1.78	13.74	30	2.54	0.78
3	19/01/2005	101.46	9.79	34.75	0.87	15.21	27.92	2.73	2.79
4	19/01/2005	101.46	10.64	34.84	4.63	14.86	9.56	0.65	2.93
5	19/01/2005	101.46	11.23	34.87	3.92	16.45	11.78	2.19	1.21
6	19/01/2005	101.46	13.92	34.93	6.59	7.23	4.21	1.38	9.19
7	19/01/2005	101.46	14.18	34.93	7.2	4.35	1.22	0.97	7.63
8	14/01/2005	101.46	14.63	35.06	6.81	5.76	2.94	0.86	5.51
9	18/01/2005	101.46	15.67	35.20	6.99	4.09	2.87	0.87	3.86

10	18/01/2005	101.46	-	-	-	2.52	1.6	0.4	2.21
1	24/02/2005	91.90	9.98	34.77	1.1	25.33	38.59	3.02	1.76
2	24/02/2005	91.90	9.92	34.76	0.92	25.25	39.51	3.6	2
3	24/02/2005	91.90	11.37	34.76	3.35	14.34	22.51	3.53	12.63
4	24/02/2005	91.90	11.6	34.77	3.71	13.93	17.81	1.77	31.82
5	24/02/2005	91.90	12.22	34.78	5.5	9.34	3.09	1.03	25.32
6	24/02/2005	91.90	12.73	34.92	5.71	11.26	7.1	1.08	6.1
7	25/02/2005	91.90	12.09	34.84	5.43	11.88	8.63	1.51	8.87
8	25/02/2005	91.90	13.41	35.05	5.87	8.72	4.86	0.87	5.35
9	25/02/2005	91.90	16.37	34.94	6.34	1.43	4.09	0.64	2.03
10	25/02/2005	91.90	15.45	34.91	5.83	0.2	3.38	0.58	1.38
11	25/02/2005	91.90	15.6	35.07	6.87	0.92	2.3	0.42	5.12
12	25/02/2005	91.90	18.49	35.20	6.85	0	0.81	0.27	2.7
1	12/03/2005	66.09	11.69	34.83	2.29	13.23	16	2.3	4.35
2	12/03/2005	66.09	10.93	34.86	2.35	13.28	11.8	2.01	4.01
3	12/03/2005	66.09	10.08	34.76	0.83	23.74	33.15	2.72	2.3
4	12/03/2005	66.09	12.97	34.75	5.48	4.63	6.12	1.45	6.95
5	12/03/2005	66.09	12.93	34.89	4.6	11.08	9.26	1.3	1.74
6	12/03/2005	66.09	13.19	34.87	5.65	8.4	9.22	1.52	5.91
7	13/03/2005	66.09	13.57	34.99	5.44	6.62	7.54	0.85	3.9
8	13/03/2005	66.09	15.4	35.05	5.96	3.82	4.65	0.51	2.51
9	13/03/2005	66.09	16.42	35.09	5.86	2.21	3.41	0.82	2.37
10	13/03/2005	66.09	15.19	35.09	5.47	5.23	4.87	0.91	1
11	13/03/2005	66.09	17.82	35.10	5.85	-	-	-	-
12	13/03/2005	66.09	17.81	35.11	5.86	1.27	2.69	0.34	1.37
1	05/04/2005	48.46	10.28	34.80	1.36	28.33	27.05	2.43	3.08
2	05/04/2005	48.46	10.04	34.78	1	27.39	26.63	2.35	2.44
3	05/04/2005	48.46	10.24	34.77	0.98	25.58	24.36	2.55	0.3
4	05/04/2005	48.46	11.95	34.83	3.82	20.37	18.52	1.52	0.91
5	05/04/2005	48.46	11.43	34.81	4.82	15.8	18.43	1.82	2.22
6	05/04/2005	48.46	13.75	34.83	6.76	7.18	10.86	1.19	4.44
7	05/04/2005	48.46	14.04	34.87	7.28	5.1	6.09	0.93	3.35
8	05/04/2005	48.46	13.72	34.84	7.3	3.44	8.05	1.12	6.2
9	05/04/2005	48.46	15.67	34.89	7.84	0	4.64	0.4	3.27
10	05/04/2005	48.46	15.64	35.11	6.85	3.48	3.59	0.5	1.09
11	05/04/2005	48.46	17.13	35.19	7.13	1.22	4.19	0.39	1.18
12	05/04/2005	48.46	20	35.46	7.5	0	3.26	0.5	0.51
1	19/05/2005	-16.60	14.23	34.86	5.85	6.86	10.03	1.02	7.13
2	19/05/2005	-16.60	13.1	34.84	4.26	20.15	23.33	1.96	1.22
3	19/05/2005	-16.60	13.45	34.84	4.66	12.04	12.94	1.64	3.51
4	19/05/2005	-16.60	14.17	34.83	5.67	8.15	15.21	0.87	2.07
5	20/05/2005	-16.60	17.17	35.26	5.21	6.75	8.95	0.82	0.95
6	20/05/2005	-16.60	18.26	35.35	5.33	1.94	6.49	0.88	1.09
7	20/05/2005	-16.60	18.75	35.37	5.62	1.91	5.41	0.49	1.26
8	20/05/2005	-16.60	18.72	35.38	5.24	1.65	5.46	0.46	1.99
9	20/05/2005	-16.60	18.67	35.41	5.29	0.89	5.42	0.29	0.55

10	20/05/2005	-16.60	18.08	35.40	5.29	1.49	5.85	0.45	0.56
1	10/06/2005	-9.58	13.92	34.81	4.7	8.46	12.29	1.76	0.76
2	10/06/2005	-9.58	13.84	34.82	4.75	7.75	11.87	1.52	1.07
3	09/06/2005	-9.58	13.73	34.81	5.16	11.87	15.28	1.77	0.45
4	09/06/2005	-9.58	14.59	34.89	4.94	5.33	9.62	1.51	1.73
5	09/06/2005	-9.58	14.56	34.88	4.74	5.34	9.8	1.43	0.85
6	09/06/2005	-9.58	15.92	35.16	5.04	2.33	7.24	1.14	2.5
7	09/06/2005	-9.58	16.55	35.24	5.09	1.69	5.91	0.87	1.22
8	09/06/2005	-9.58	16.03	35.14	5.13	3.56	7.84	1.07	1.79
9	09/06/2005	-9.58	15.77	35.08	5.04	3.64	9.01	1.11	1.87
10	09/06/2005	-9.58	17.57	35.37	4.9	0.89	5.6	0.81	0.36
11	09/06/2005	-9.58	17.11	35.31	4.92	1.2	4.42	0.73	0.59
12	09/06/2005	-9.58	16.63	35.23	5.01	1.15	3.69	0.99	0.27
1a	23/07/2005	1.11	13.12	34.87	3.68	8.81	10.82	1.06	0.78
2a	23/07/2005	1.11	12.95	34.87	3.77	7.98	10.08	0.97	1.32
3a	24/07/2005	1.11	12.7	34.84	2.14	12.3	16.52	1.72	0.96
4a	24/07/2005	1.11	14.15	34.98	4.04	3.65	6.25	0.74	2.99
5a	24/07/2005	1.11	14.85	35.13	3.9	2.4	3.5	0.8	1.65
6a	24/07/2005	1.11	15.54	35.23	3.79	1.88	2.58	0.54	0.83
7a	24/07/2005	1.11	15.77	35.26	3.81	1.48	4.23	0.38	1.08
8a	24/07/2005	1.11	15.28	35.21	3.88	-	-	-	-
9a	24/07/2005	1.11	16.75	35.34	3.7	1.75	6.12	0.31	1.01
10a	24/07/2005	1.11	17.5	35.38	3.72	1.38	5.33	0.34	0.82
11a	24/07/2005	1.11	15.95	35.29	3.78	1.63	5.66	0.37	0.58
12a	24/07/2005	1.11	-	-	-	1.63	4.34	0.4	0.66
1	24/08/2005	-29.36	13.63	34.89	4.39	6.7	11.13	1.05	0.82
2	24/08/2005	-29.36	13.46	34.89	4.41	7.49	11.15	1.13	1.66
3	24/08/2005	-29.36	13.46	34.88	4.59	7.07	9.3	1.19	3.66
4	24/08/2005	-29.36	14.55	35.20	4.8	2.11	5.79	0.54	1.31
5	24/08/2005	-29.36	15.02	35.25	4.68	1.91	6.17	0.48	3.75
6	24/08/2005	-29.36	15.15	35.27	4.79	1.46	6.49	0.54	2.46
7	24/08/2005	-29.36	15.77	35.34	4.49	2.39	6.8	0.5	0.8
8	24/08/2005	-29.36	15.99	35.39	4.48	2.06	5.89	0.43	0.62
9	25/08/2005	-29.36	16.03	35.40	4.49	1.98	5.51	0.55	0.75
10	25/08/2005	-29.36	15.94	35.38	4.38	2.29	6	0.49	0.47
1	22/09/2005	25.43	9.89	34.78	0.78	24.69	35.64	3.78	4
2	22/09/2005	25.43	9.84	34.77	0.89	27.14	34.18	3.96	3.94
3	22/09/2005	25.43	11.27	34.85	3.7	8.45	9.47	1.28	1.83
4	22/09/2005	25.43	14.05	34.93	4.17	6.95	5.15	0.71	2.15
5	22/09/2005	25.43	14.05	35.16	4.03	6	9.26	0.8	1.31
6	22/09/2005	25.43	15.04	35.25	4.45	1.83	3.67	0.63	2.03
7	21/09/2005	25.43	15.47	35.32	4.37	1.55	5.42	0.53	0.6
8	21/09/2005	25.43	15.63	35.33	4.4	1.1	6.6	0.48	0.55
9	21/09/2005	25.43	15.49	35.31	4.47	1.33	6.19	0.46	0.99
10	21/09/2005	25.43	15.52	35.33	4.41	1.46	3.9	0.53	0.58
11	21/09/2005	25.43	15.43	35.32	4.47	2.28	2.63	0.52	0.7

12	21/09/2005	25.43	15.57	35.34	4.42	1.25	2.51	0.58	0.44
1	26/10/2005	56.65	9.84	34.76	1.69	19.78	31.23	1.75	2.07
2	26/10/2005	56.65	9.85	34.76	1.06	21.23	33.96	2.31	1.14
3	26/10/2005	56.65	12.93	34.80	3.32	5.4	15.94	1.14	2.87
4	26/10/2005	56.65	12.75	34.86	3.82	6.51	8.46	1	2.14
5	26/10/2005	56.65	12.86	34.98	3.84	8.58	8.62	0.96	2.3
6	26/10/2005	56.65	14.52	35.01	4.33	1.03	4.6	0.42	3.75
7	25/10/2005	56.65	16.15	35.27	4.17	0	4.71	0.24	0.5
8	25/10/2005	56.65	16.41	35.40	4.11	0	3.11	0.36	0.48
9	25/10/2005	56.65	16.19	35.37	4.21	0	3.32	0.29	0.6
10	25/10/2005	56.65	16.33	35.36	4.13	0	5.45	0.28	0.57
11	25/10/2005	56.65	16.19	35.35	4.23	0.12	4.82	0.31	0.62
12	25/10/2005	56.65	16.25	35.38	4.16	0.18	3.73	0.38	0.4
1	13/12/2005	118.20	9.37	34.71	1.46	22.44	31.94	2.25	2.73
2	13/12/2005	118.20	10.6	34.71	2.26	14.5	35.13	2.23	13.3
3	13/12/2005	118.20	11.41	34.73	2.84	6.49	24.09	1.45	12.78
4	13/12/2005	118.20	12.13	34.77	3.15	9.96	9.82	1.3	10.18
5	13/12/2005	118.20	11.38	34.78	3.24	10.97	14.73	1.18	12.99
6	13/12/2005	118.20	13.96	35.02	3.46	1.1	4.42	0.56	2.59
7	13/12/2005	118.20	14.61	35.09	3.39	1.57	4.19	0.35	5.07
8	13/12/2005	118.20	14.96	35.11	3.58	0.36	2.93	0.32	5.63
9	14/12/2005	118.20	15.21	35.19	3.36	1.89	4.28	0.56	7.67
10	14/12/2005	118.20	18.49	35.48	3.11	0	3.81	0.35	1.19
11	14/12/2005	118.20	18.76	35.52	3.09	0	4.6	0.26	0.13
12	14/12/2005	118.20	18.34	35.50	3.12	0	2.97	0.18	0.1
1	17/01/2006	119.47	9.89	34.76	2.52	19.9	29.17	2.22	6
2	17/01/2006	119.47	9.73	34.76	2.13	17.23	21.41	2.06	5.96
3	17/01/2006	119.47	9.84	34.76	2.23	18.78	13.78	1.96	10.15
4	17/01/2006	119.47	10.89	34.85	2.87	15.78	12.15	1.85	1.24
5	17/01/2006	119.47	15.15	34.68	3.45	0.7	1.9	0.65	4.93
6	17/01/2006	119.47	14.53	34.73	4.09	2.81	7.45	0.69	6.08
7	17/01/2006	119.47	17.13	35.12	4.04	0.16	4.87	0.26	0.67
8	17/01/2006	119.47	14.85	35.11	3.67	2.48	2.13	0.5	0.97
9	17/01/2006	119.47	-	-	-	0.88	4.89	0.49	1.98
10	17/01/2006	119.47	14.93	35.00	3.97	1.04	4.72	0.49	1.17
11	17/01/2006	119.47	-	-	-	0	2.02	0.2	0.26
12	16/01/2006	119.47	-	-	-	0.79	7.73	0.08	0.43
1	25/02/2006	90.65	13.03	34.83	3.72	7.08	3.56	1.14	18.62
2	25/02/2006	90.65	10.27	34.80	1.83	23.91	23.51	2.58	2.52
3	25/02/2006	90.65	10.27	34.78	1.31	26.41	28.51	2.42	1.76
4	25/02/2006	90.65	10.44	34.80	2.07	20.9	11.98	1.63	1.61
5	25/02/2006	90.65	10.94	34.82	2.13	21	9.7	1.6	0.18
6	25/02/2006	90.65	13.09	34.90	2.69	13.18	7.77	1.63	2.53
7	25/02/2006	90.65	16.3	34.91	2.99	6.6	4.24	0.94	1.74
8	24/02/2006	90.65	16.83	34.96	3.12	1.04	3.04	0.44	1.82
9	24/02/2006	90.65	13.6	35.03	2.88	9.83	4.13	1.01	3.25

10	24/02/2006	90.65	14.84	35.12	2.92	6.44	3.55	1.04	1.07
11	24/02/2006	90.65	-	-	-	6.64	3.3	0.55	-
12	24/02/2006	90.65	-	-	-	0.3	3.7	0.31	0.27
1	14/03/2006	75.41	9.96	34.78	1.67	19.47	33.37	2.54	4.93
2	14/03/2006	75.41	9.93	34.77	1.41	21.62	41.56	3.04	9.62
3	14/03/2006	75.41	11.21	34.77	1.94	16.91	23.55	2.47	7.89
4	14/03/2006	75.41	12.67	34.78	2.98	10.24	14.03	1.76	9.04
5	14/03/2006	75.41	11.74	34.78	2.76	12.16	15.27	1.55	8.47
6	14/03/2006	75.41	12.2	34.80	3.08	14.35	13.28	1.57	5.55
7	14/03/2006	75.41	12.93	34.80	3.52	8.53	7.66	1.04	10.4
8	14/03/2006	75.41	14.12	34.82	3.64	3.09	3.21	0.67	8.51
9	14/03/2006	75.41	15.18	35.12	3.64	3.38	3.72	0.74	3.99
10	14/03/2006	75.41	19.87	35.57	3.27	-	-	-	-
11	14/03/2006	75.41	20.2	35.63	3.22	-	-	-	0.22
12	14/03/2006	75.41	19.98	35.60	3.24	-	-	-	0.23
1	04/04/2006	-2.75	10.68	34.78	1.21	12.51	32.57	2.83	7.43
2	04/04/2006	-2.75	10.48	34.76	0.92	16.11	42.17	3.83	4.15
3	04/04/2006	-2.75	10.3	34.77	0.74	23.83	28.63	2.91	4.48
4	04/04/2006	-2.75	10.32	34.79	2.21	-	-	-	7.36
1	28/05/2006	-2.75	13.96	34.73	4.48	4.1	6.41	0.91	1.61
2	28/05/2006	-2.75	13.74	34.72	4.4	4.72	6.71	0.9	1.21
3	28/05/2006	-2.75	12.94	34.81	3.66	7.88	11.55	1.26	0.67
4	28/05/2006	-2.75	13.64	34.78	4.56	5.74	3.64	0.77	0.56
5	28/05/2006	-2.75	13.24	34.76	3.51	15.1	11.12	1.79	0.78
6	28/05/2006	-2.75	13.08	34.72	3.72	8.45	14.01	1.55	0.31
7	28/05/2006	-2.75	13.39	34.77	4.14	6.82	8.12	1.26	3.13
8	28/05/2006	-2.75	15.56	35.24	4.44	3.37	6.38	0.5	1.75
9	28/05/2006	-2.75	15.48	35.21	4.44	3.22	6.66	0.53	0.93
10	28/05/2006	-2.75	16.82	35.38	4.35	1.43	5.27	0.49	0.44
1	27/06/2006	-14.57	13.04	34.83	4.1	10.27	15.44	1.78	3.35
2	27/06/2006	-14.57	12.88	34.85	3.89	11.14	18.42	1.38	2.82
3	27/06/2006	-14.57	13.33	34.83	4.42	7.58	10.01	1.31	3.74
4	27/06/2006	-14.57	13.54	34.88	4.31	7.03	10.15	1.02	2.51
5	27/06/2006	-14.57	13.61	34.90	4.39	6.35	9.33	0.89	2.91
6	27/06/2006	-14.57	13.01	34.83	4.21	8.77	11.16	1.28	1.82
7	28/06/2006	-14.57	13.56	34.99	4.51	4.42	6.57	1.09	2.32
8	28/06/2006	-14.57	13.85	34.95	4.45	5.36	7.34	0.89	3.09
9	28/06/2006	-14.57	15.24	35.27	4.39	2.46	4.97	0.69	1.03
10	28/06/2006	-14.57	15.09	35.18	4.5	1.56	4.46	1.65	1.19
11	28/06/2006	-14.57	14.95	35.16	4.53	2	7.43	1.52	1.25
1	02/08/2006	29.26	10.66	34.83	0.22	20.59	47.82	2.04	1.2
2	02/08/2006	29.26	12.14	34.81	1.9	17.05	40.5	1.47	3.18
3	02/08/2006	29.26	13	34.79	4.75	6.54	4.17	0.73	10.78
4	02/08/2006	29.26	13.11	34.81	4.82	6.27	6.17	0.8	7.45
5	02/08/2006	29.26	12.77	34.93	4.02	9.76	12.32	1.25	0.84
6	02/08/2006	29.26	13.66	35.05	4.62	4.39	6.4	0.77	1.41

7	02/08/2006	29.26	13.67	35.05	4.65	3.84	5.98	0.73	1.47
9	02/08/2006	29.26	14.44	35.15	4.48	4	6.07	0.72	0.65
10	02/08/2006	29.26	14.55	35.16	4.48	3.11	4.93	0.69	0.6
1	01/09/2006	60.00	11.4	34.82	1.33	15.84	37.79	2.07	1.96
2	01/09/2006	60.00	13.11	34.83	4.47	5.52	6.51	0.9	5.33
3	01/09/2006	60.00	13.16	34.95	4.53	4.77	8.38	0.82	6.28
4	31/08/2006	60.00	13.62	35.02	4.77	5.15	7.62	0.81	6.32
5	31/08/2006	60.00	12.85	34.97	3.92	12.6	11.22	1.17	2.06
6	31/08/2006	60.00	13.88	35.11	4.55	5.89	4.72	0.83	4.24
7	31/08/2006	60.00	15.01	35.22	4.63	2.52	7.13	0.59	1.98
8	31/08/2006	60.00	15.85	35.33	4.47	2.84	6.74	0.6	0.61
9	31/08/2006	60.00	15.57	35.31	4.51	2.64	6.51	0.6	0.68
10	31/08/2006	60.00	-	-	4.39	2.68	5.9	0.73	0.74
1	18/12/2006	82.44	9.34	34.68	1.71	18.67	27.26	1.98	2.46
2	18/12/2006	82.44	9.38	34.68	1.54	22	30.91	1.79	11.95
3	18/12/2006	82.44	11.21	34.66	3.27	9.91	17.51	1.61	10.44
4	18/12/2006	82.44	12.39	34.70	4.8	5.6	12.94	1.89	5.8
5	19/12/2006	82.44	13.19	34.69	4.89	4.38	9.19	1.74	10.74
6	19/12/2006	82.44	13.18	35.00	3.98	7.45	11.39	1.24	0.71
7	19/12/2006	82.44	13.18	35.13	3.7	8.73	8.33	0.73	18.92
8	19/12/2006	82.44	14.8	34.99	4.58	1.35	6.97	0.81	7.84
9	19/12/2006	82.44	15.06	35.07	4.28	2.67	5.82	0.67	6.45
10	19/12/2006	82.44	15.35	34.97	5.17	0.08	3.98	0.32	8.57
11	19/12/2006	82.44	18.41	35.32	4.16	1.06	4.36	0.19	2.53
12	19/12/2006	82.44	19.42	35.37	4.28	0.09	5.68	0	1.36
1	14/01/2007	107.31	9.48	34.70	0.31	16.58	33.05	2.08	2.43
2	14/01/2007	107.31	9.59	34.69	0.51	16.28	34.66	1.63	2.3
3	14/01/2007	107.31	10.61	34.69	1.74	15.92	22.26	1.82	14.84
4	14/01/2007	107.31	11.48	34.73	2.85	14.79	16.98	1.19	2.49
5	13/01/2007	107.31	14.19	34.73	4.68	6.7	13.34	1.14	6.67
6	13/01/2007	107.31	17.75	35.19	4.37	0.85	3.37	0.26	1.31
7	13/01/2007	107.31	18.6	35.25	4.41	0	1.39	0.35	0.93
8	13/01/2007	107.31	-	-	-	1.46	2.55	0.03	1.77
9	13/01/2007	107.31	15.87	35.10	4.43	1.86	6.19	0.56	3.17
10	13/01/2007	107.31	18.74	35.27	4.42	1.87	3.68	1.23	3.22
11	13/01/2007	107.31	19.38	35.28	4.4	0.15	2.02	0.22	0.37
1	01/03/2007	78.64	11.05	34.75	1.79	-	-	-	8.75
2	01/03/2007	78.64	9.81	34.73	0.15	-	-	-	3.14
3	01/03/2007	78.64	10.28	34.75	1.88	-	-	-	5.46
4	28/02/2007	78.64	11.87	34.79	3.28	-	-	-	1.95
5	28/02/2007	78.64	14.16	34.75	5.02	-	-	-	6.54
6	28/02/2007	78.64	13.46	35.10	3.64	-	-	-	1.21
7	28/02/2007	78.64	17.8	34.89	8.11	-	-	-	7.19
8	28/02/2007	78.64	13.04	34.91	3.04	-	-	-	3.64
9	28/02/2007	78.64	16.65	35.30	3.72	-	-	-	-
10	28/02/2007	78.64	19.27	35.29	4.44	1.76	3.48	0.09	-

11	28/02/2007	78.64	21.27	35.46	4.15	-	-	-	-
1	23/03/2007	69.12	11.62	34.76	3.55	6.47	12.33	1.43	11.52
2	23/03/2007	69.12	10.66	34.75	2.14	18.51	21.24	2.14	1.81
3	23/03/2007	69.12	10.4	34.74	1.69	17.39	17.34	1.88	5.15
4	23/03/2007	69.12	12.53	34.76	4.43	3.69	3.21	0.88	5.02
5	22/03/2007	69.12	12.96	34.82	3.42	5.16	4.53	0.9	7.75
6	22/03/2007	69.12	15.07	34.91	5.19	0.68	3.32	0.37	6.45
7	22/03/2007	69.12	16.47	35.01	4.34	0.49	4.7	0.49	1.6
8	22/03/2007	69.12	-	-	-	0.1	5.02	0.34	3.15
9	22/03/2007	69.12	-	-	-	1.51	6.52	0.26	1.02
10	22/03/2007	69.12	16.86	35.24	4.13	0.29	6.13	0.21	1.88
11	04/05/2007	35.05	11.09	34.78	1.1	23.47	34.46	2.98	-
12	04/05/2007	35.05	10.79	34.78	1.01	28.31	33.59	3.22	-
3	04/05/2007	35.05	11.05	34.83	1.82	24.06	10.52	2.34	-
4	04/05/2007	35.05	13.24	34.76	2.22	8.36	17.87	2.83	-
5	04/05/2007	35.05	12.95	34.98	3.13	14.3	8.5	1.84	-
6	04/05/2007	35.05	15.69	35.18	3.91	8.13	4.81	1.3	-
7	04/05/2007	35.05	16.12	35.11	3.53	9.81	7.15	1.19	-
8	04/05/2007	35.05	17.57	35.28	4.28	3.08	2.49	0.48	-
9	04/05/2007	35.05	18.93	35.41	4.07	2.6	1.48	0.34	-
10	04/05/2007	35.05	19.03	35.42	3.62	1.24	3.43	0.38	-
11	03/05/2007	35.05	18.91	35.38	3.62	1.72	3.3	0.34	-
12	03/05/2007	35.05	19.06	35.38	3.68	1.1	2.29	0.63	-
1	03/07/2007	-6.93	13.04	34.86	3.59	11.48	13.17	1.17	0.55
2	03/07/2007	-6.93	13.09	34.84	3.78	9.96	11.82	1.19	0.54
3	03/07/2007	-6.93	13.04	34.89	4.11	10.23	6.76	1.07	1.06
4	03/07/2007	-6.93	13.15	34.89	4.36	6.99	6.87	1.07	3.07
5	03/07/2007	-6.93	13.68	34.94	3.85	10.92	11.12	1.15	0.83
6	03/07/2007	-6.93	13.49	34.90	4.31	9.19	10.95	1.1	3.39
7	03/07/2007	-6.93	13.63	34.92	4.26	7.31	8.36	0.89	2.9
8	03/07/2007	-6.93	15.42	35.25	4.25	3.83	4.87	0.6	1.22
9	03/07/2007	-6.93	16.58	35.33	4.12	3.48	4.94	0.51	1.86
10	03/07/2007	-6.93	16.82	35.34	4.24	2.32	4.31	0.27	1.01
11	03/07/2007	-6.93	16.31	35.36	4.22	2.72	4.82	0.28	0.78
12	03/07/2007	-6.93	16.06	35.30	3.75	2.74	4.38	0.22	0.91
1	08/08/2007	-12.68	13.11	34.59	4.09	7.05	6.34	1.45	3.56
2	08/08/2007	-12.68	13.05	34.64	4.34	6.33	6.12	0.65	4.07
3	08/08/2007	-12.68	13.06	34.75	4.11	7.44	8.62	0.99	3.2
4	08/08/2007	-12.68	13.05	34.87	4.39	6.13	6.16	0.96	4.76
5	08/08/2007	-12.68	13.13	34.87	4.34	5.77	5.94	0.91	3.36
6	08/08/2007	-12.68	14.44	35.14	4.09	4.41	5.55	0.77	1.75
7	08/08/2007	-12.68	15.25	35.22	4.21	2.73	6.03	0.6	1.09
8	08/08/2007	-12.68	15.41	35.24	4.21	3.39	5.46	0.88	1.18
9	08/08/2007	-12.68	16.2	35.31	4.12	3.42	5.9	0.48	0.99
10	08/08/2007	-12.68	15.95	35.29	4.17	3.41	6.25	0.44	1.28
11	08/08/2007	-12.68	16.44	35.38	4.2	2.84	6.18	0.57	1.47

12	08/08/2007	-12.68	16.54	35.40	3.76	2.99	6.31	0.6	1.38
1	26/09/2007	20.82	10.46	34.84	1.9	22.52	30.11	2.59	1.43
2	26/09/2007	20.82	10.34	34.83	2.31	19.8	24.66	2.59	1.42
3	26/09/2007	20.82	10.73	34.89	4.86	16.42	7.19	1.66	4.26
4	26/09/2007	20.82	11.23	34.92	-	17.9	10.19	1.69	-
5	26/09/2007	20.82	12.89	34.95	4.4	11.81	4.49	1.45	9.34
8	26/09/2007	20.82	16.99	35.43	6.33	0	0	0.74	4.75
9	26/09/2007	20.82	16.76	35.41	6.29	0	0	0.61	4.47
10	26/09/2007	20.82	16.84	35.45	6.25	0.41	0	0.31	9.01
11	26/09/2007	20.82	16.58	35.47	-	0	0	0.7	-
12	26/09/2007	20.82	16.89	35.47	-	0.23	0	0.29	-
1	01/11/2007	107.86	14.31	34.75	5.01	1.31	3.33	0.38	-
2	01/11/2007	107.86	13.62	34.73	4.61	9.54	9.26	1.26	-
3	01/11/2007	107.86	11.72	34.75	2.39	15.61	9.93	1.96	-
4	01/11/2007	107.86	13.36	34.86	4.31	6.06	4.19	0.67	-
5	01/11/2007	107.86	13.35	34.89	4.1	6.89	3.94	0.57	-
6	01/11/2007	107.86	13.83	34.88	4.8	2.44	3.33	0.19	-
7	31/10/2007	107.86	15.21	35.08	4.73	1.52	4.56	0.23	-
8	31/10/2007	107.86	14.5	35.07	4.24	3.23	4.86	0.25	-
9	31/10/2007	107.86	15.68	35.23	4.49	1.73	3.91	0.12	-
10	31/10/2007	107.86	16.97	35.39	4.23	1.33	4.5	0	-
11	31/10/2007	107.86	16.8	35.37	4.23	1.57	3.72	0.16	-
12	31/10/2007	107.86	17.14	35.40	3.65	0.81	4.31	0.02	-
1	11/12/2007	93.31	12.11	34.71	3.49	12.25	5.72	2.54	-
2	11/12/2007	93.31	10.82	34.69	2.43	14.9	9.49	3	-
3	11/12/2007	93.31	10.63	34.70	2.25	17.71	9.92	1.77	-
4	11/12/2007	93.31	11.56	34.74	2.93	12.87	2.88	1.46	-
5	11/12/2007	93.31	11.4	34.71	2.99	8.32	0.02	0.78	-
6	11/12/2007	93.31	13.05	34.84	4.03	0.89	0	0.61	-
7	11/12/2007	93.31	13.34	35.08	3.07	9.23	0	0.76	-
8	11/12/2007	93.31	13.97	35.08	3.21	6.48	0	0.65	-
9	11/12/2007	93.31	17.4	35.30	3.71	1.03	0	0.65	-
11	11/12/2007	93.31	17.98	35.38	3.46	0.57	0.21	3.17	-
12	11/12/2007	93.31	18.02	35.41	3.37	0.3	0	0.36	-
1	24/01/2008	164.75	10.26	34.77	1.92	23.72	16.16	2.22	-
2	24/01/2008	164.75	10.62	34.76	2.22	-	11.73	2.63	-
3	24/01/2008	164.75	11.65	34.76	3.83	11.36	4.81	1.38	-
4	24/01/2008	164.75	10.88	34.79	3.7	14.29	5.4	1.24	-
5	24/01/2008	164.75	13.03	34.82	3.81	11.48	3.6	1.27	-
6	24/01/2008	164.75	12.08	34.73	4.21	12.93	11.41	1.59	-
7	24/01/2008	164.75	13.18	34.86	4.03	11.44	5.26	1.04	-
8	24/01/2008	164.75	14.78	34.92	4.33	7.1	1.94	0.66	-
9	24/01/2008	164.75	14.56	34.93	4.2	6.21	4.51	0.54	-
10	24/01/2008	164.75	14.46	34.88	4.69	10.21	1.02	0.5	-
12	24/01/2008	164.75	20.34	35.47	3.8	1.65	0.67	0.33	-
1	27/02/2008	89.55	10.15	34.74	0.28	23.71	20.29	3.12	-

2	27/02/2008	89.55	10.13	34.73	0.27	24.16	24.65	3.45	-
3	27/02/2008	89.55	9.83	34.73	0.92	25.22	21.48	2.64	-
4	27/02/2008	89.55	10.31	34.73	1.3	23.12	20.91	2.83	-
5	27/02/2008	89.55	11.86	34.72	3.28	16.74	15.78	2.35	-
6	27/02/2008	89.55	14.15	34.79	5.46	7.7	5.45	1.11	-
7	27/02/2008	89.55	14.43	34.84	5.1	8.38	5	0.97	-
8	27/02/2008	89.55	13.96	34.74	5.98	6.67	6.68	1.01	-
9	27/02/2008	89.55	16.18	34.82	6.72	0	1.53	0.44	-
10	27/02/2008	89.55	14.79	34.89	6.61	1.54	0.42	0.57	-
11	27/02/2008	89.55	19.77	35.25	5.41	0	1.28	0.2	-
12	27/02/2008	89.55	19.74	35.26	5.34	0.43	1.82	0.51	-
1	19/03/2008	101.00	9.92	34.76	0.23	27.53	37.96	3.41	-
2	19/03/2008	101.00	10.1	34.76	0.74	24.89	33.01	3	-
3	19/03/2008	101.00	10.47	34.77	1.15	26.73	27.12	2.7	-
4	19/03/2008	101.00	11.2	34.77	2.96	19.08	4.96	2.16	-
5	19/03/2008	101.00	11.49	34.79	2.68	11.96	3	1.98	-
6	19/03/2008	101.00	10.49	34.76	2.09	26.66	21.16	2.4	-
7	19/03/2008	101.00	12.95	34.89	4.09	9.73	4.71	1.36	-
8	19/03/2008	101.00	15.56	35.12	4.41	3.28	1.17	0.66	-
9	19/03/2008	101.00	17.24	35.19	4.68	1.04	0	0.39	-
10	19/03/2008	101.00	13.65	34.95	4.41	5.66	2.75	0.93	-
11	19/03/2008	101.00	16.04	35.28	3.81	3.16	0.92	0.53	-
12	19/03/2008	101.00	16.19	34.98	3.72	5.16	1	0.49	-
1	09/05/2008	-65.64	12.69	34.79	4.681	6.51	12.49	0.85	-
2	09/05/2008	-65.64	13.04	34.79	6.131	2.99	5.1	0.43	-
3	09/05/2008	-65.64	12.81	34.60	4.996	1.09	3.24	0.27	-
4	08/05/2008	-65.64	13.27	34.22	3.334	9.63	3.09	0.88	-
5	08/05/2008	-65.64	12.67	34.46	3.758	11.84	8.84	1.47	-
6	08/05/2008	-65.64	12.98	34.86	5.495	7.51	5.69	1.1	-
7	08/05/2008	-65.64	15.64	35.15	5.575	7.19	3.86	0.51	-
8	08/05/2008	-65.64	15.84	35.18	5.525	4.53	4.91	0.51	-
9	08/05/2008	-65.64	14.22	34.95	5.521	8.88	4	0.86	-
10	08/05/2008	-65.64	13.21	34.80	5.361	6.66	4.36	1.44	-
11	08/05/2008	-65.64	16.89	35.28	5.02	2.93	4.53	0.65	-
12	08/05/2008	-65.64	18.67	35.48	4.676	1.62	3.48	0.49	-
1	18/08/2008	11.85	11.78	34.87	3	18.92	26.68	1.83	1.635
2	18/08/2008	11.85	12.23	34.86	3.39	18.98	24	1.86	2.369
3	18/08/2008	11.85	13.61	34.87	6.03	4.14	2.22	1.04	6.319
4	18/08/2008	11.85	13.95	34.96	6	2.72	3.62	0.54	3.343
5	18/08/2008	11.85	13.82	34.83	6.6	1.23	1.68	0.48	13.771
6	18/08/2008	11.85	14.34	34.97	6	1.09	1.81	0.21	3.95
7	18/08/2008	11.85	15.97	35.36	5.75	2.36	1.65	0.03	2.629
8	18/08/2008	11.85	16.12	35.39	5.81	2.23	0.1	0.11	2.364
9	17/08/2008	11.85	15.95	35.36	5.72	2.49	2.37	0.28	1.019
10	17/08/2008	11.85	16.41	35.41	5.59	3.83	1.71	0.2	1
11	17/08/2008	11.85	16.37	35.43	5.31	2.84	1.17	0.26	1.276

12	17/08/2008	11.85	16.53	35.43	5.23	1.93	1.68	0.26	0.705
1	28/09/2008	-14.80	12.28	34.85	2.41	19.02	25.79	2.11	0.35
2	28/09/2008	-14.80	13.15	34.89	3.28	11.02	17.16	1.37	0.28
3	28/09/2008	-14.80	14.4	34.84	6.08	3	7.93	1.69	3.5
4	28/09/2008	-14.80	14.33	34.82	5.95	3.23	8.6	0.74	3.47
5	28/09/2008	-14.80	15.12	35.30	6.04	-	-	-	-
6	28/09/2008	-14.80	15.59	35.39	5.85	1.26	4.24	0.36	1.2
7	28/09/2008	-14.80	15.59	35.39	5.83	1.29	4.11	0.44	0.96
8	28/09/2008	-14.80	16.11	35.44	5.65	2.2	4.06	0.55	0.39
9	28/09/2008	-14.80	16.29	35.46	5.61	2.33	4.54	0.44	0.33
10	27/09/2008	-14.80	15.99	35.44	5.67	2.38	5.34	0.41	1
11	27/09/2008	-14.80	16.16	35.46	5.7	3.59	12.92	0.32	0.62
12	27/09/2008	-14.80	16.25	35.46	5.7	2.77	4.98	0.56	0.72
1	06/10/2008	117.58	11.26	34.84	0.94	-	-	-	-
2	06/10/2008	117.58	10.78	34.87	1.56	-	-	-	-
3	06/10/2008	117.58	13.43	34.90	5.29	-	-	-	-
4	07/10/2008	117.58	11.66	34.97	4.96	-	-	-	-
5	07/10/2008	117.58	13.3	35.11	5.44	-	-	-	-
6	07/10/2008	117.58	15.7	35.43	5.74	-	-	-	-
7	07/10/2008	117.58	15.84	35.45	5.56	-	-	-	-
8	07/10/2008	117.58	16.02	35.46	5.55	-	-	-	-
9	07/10/2008	117.58	16.12	35.46	5.61	-	-	-	-
10	07/10/2008	117.58	16.26	35.47	5.56	-	-	-	-
11	07/10/2008	117.58	16.13	35.47	5.62	-	-	-	-
12	07/10/2008	117.58	16.13	35.47	5.62	-	-	-	-
1	21/01/2009	92.93	11.56	34.76	3.49	23.06	40.14	2.26	2.6
2	21/01/2009	92.93	10.64	34.75	2.1	24.28	40.45	2.51	1.32
3	21/01/2009	92.93	10.44	34.77	2.46	25.34	26.24	2.23	-
4	21/01/2009	92.93	11.31	34.82	3.91	19.3	14.62	1.63	-
5	21/01/2009	92.93	10.78	34.80	3.37	22.81	20.61	1.83	1.14
6	21/01/2009	92.93	12.66	35.04	4.3	12.67	8.95	1.01	-
8	20/01/2009	92.93	15.72	35.18	5.48	2.75	4.91	0.28	4.41
9	20/01/2009	92.93	17.36	35.19	5.64	0.73	1.97	0.34	3.02
10	20/01/2009	92.93	17.15	35.26	5.51	-	-	-	-
11	20/01/2009	92.93	17.32	35.32	5.31	1.32	2.45	0.33	2.45
12	20/01/2009	92.93	18.17	35.41	5.35	0.65	2.1	0.1	1.27
2	19/02/2009	100.47	10.66	34.80	2.76	-	-	-	10.17
3	19/02/2009	100.47	10.9	34.80	2.38	-	-	-	10.38
4	19/02/2009	100.47	12.83	34.86	4.25	-	-	-	5.76
5	19/02/2009	100.47	13.57	34.95	4.43	-	-	-	1.21
6	19/02/2009	100.47	14.39	34.93	5.13	-	-	-	6.18
7	19/02/2009	100.47	14.16	35.07	4.69	-	-	-	1.65
8	19/02/2009	100.47	14.19	34.98	5.52	-	-	-	6.31
9	19/02/2009	100.47	14.99	35.27	5	-	-	-	1.79
10	19/02/2009	100.47	16.64	35.22	5.73	-	-	-	1.53
11	19/02/2009	100.47	20.15	35.48	5.09	-	-	-	0.69

12	19/02/2009	100.47	20.17	35.50	5.16	-	-	-	0.51
1	17/03/2009	74.29	10.12	34.81	0.5	28.15	29.45	2.46	0.43
2	17/03/2009	74.29	10.04	34.81	0.26	28.77	32.1	2.66	0.35
3	17/03/2009	74.29	10.3	34.84	3.44	20.86	8.89	1.62	1.4
4	17/03/2009	74.29	12.9	34.84	4.38	7.84	1.9	1.12	9.05
5	17/03/2009	74.29	11.81	34.92	3.12	16.2	7.28	1.61	1.87
6	17/03/2009	74.29	12.82	34.97	3.75	14.55	7.49	1.42	1.2
7	17/03/2009	74.29	15.65	34.90	5.84	5.62	0.87	0.62	3.14
8	17/03/2009	74.29	14.01	34.99	4.51	10.08	4.86	1.07	0.75
9	17/03/2009	74.29	15.95	34.99	5.93	1.78	0.38	0.54	26.5
10	17/03/2009	74.29	14.06	34.95	5.61	7.27	4.58	0.89	7.2
1	16/04/2009	31.64	10.33	34.80	0.89	-	-	-	-
2	16/04/2009	31.64	10.52	34.80	1.58	25.84	30.02	2.08	-
3	16/04/2009	31.64	10.22	34.81	1.76	26.47	22.24	2.09	-
4	16/04/2009	31.64	10.18	34.81	2.91	28.03	13	1.86	-
5	16/04/2009	31.64	11.65	34.82	3.45	19.71	7.82	1.51	-
6	15/04/2009	31.64	11.84	34.79	4.41	12.81	2.61	1.45	-
7	15/04/2009	31.64	13.92	35.20	4.43	11.07	6.6	0.83	-
8	15/04/2009	31.64	15.29	35.14	5.87	9.48	4.43	0.78	-
9	15/04/2009	31.64	14.77	35.18	4.75	9.95	4.71	0.82	-
10	15/04/2009	31.64	16.64	35.15	5.54	8.3	1.47	0.49	-
11	15/04/2009	31.64	17.6	35.27	5.24	3.87	2.06	0.51	-
12	15/04/2009	31.64	17.95	35.31	5.17	2.68	1.7	0.4	-
1	18/06/2009	-27.17	14.4	34.89	5.16	6.74	11.14	0.63	-
2	18/06/2009	-27.17	14.43	34.89	5.46	5.87	10.07	0.89	-
3	18/06/2009	-27.17	14.63	35.03	5.5	6.16	6.74	0.44	-
4	18/06/2009	-27.17	14.95	34.97	5.54	5.01	4.73	0.37	-
5	18/06/2009	-27.17	15.24	35.08	5.83	2.82	6.2	0.28	-
6	18/06/2009	-27.17	15.32	35.19	5.73	2.88	6.26	0.29	-
7	18/06/2009	-27.17	15.83	35.29	5.47	2.55	5.03	0.12	-
8	18/06/2009	-27.17	15.81	35.25	5.82	6.36	6.31	0.39	-
9	18/06/2009	-27.17	15.46	35.20	5.48	4.42	4.33	0.03	-
11	18/06/2009	-27.17	18.16	35.45	5.28	0.86	2.46	0	-
1	14/07/2009	0.52	13.78	34.85	5.11	12.86	11.16	1.05	1.1
2	14/07/2009	0.52	14.09	34.79	5.53	9.18	8.29	0.65	2.71
3	14/07/2009	0.52	14.24	34.76	6.03	3.95	3.7	0.3	3.89
4	14/07/2009	0.52	13.92	34.78	6.24	6.63	7.69	0.79	1.56
5	14/07/2009	0.52	13.98	34.89	6.24	7.8	6.27	0.62	1.94
6	14/07/2009	0.52	14.6	35.03	6.09	7.35	6.79	0.41	-
7	14/07/2009	0.52	15.44	35.18	6.43	1.82	4.09	0.01	3.93
8	14/07/2009	0.52	15.85	35.25	6.21	9.01	1.82	0.14	2.47
9	14/07/2009	0.52	15.39	35.19	6.33	3.585	1.46	0.13	4.5
10	14/07/2009	0.52	15.39	35.20	6.33	0.86	1.64	0.26	4.55
11	14/07/2009	0.52	15.8	35.28	6.13	0.87	2.79	0.29	2.23
12	15/07/2009	0.52	16.01	35.29	5.93	2.45	2.7	0.34	0.56

Averaged station details - Station 11

Early summer (2004-2009)

Depth	Temperature	Salinity	Oxygen	Nitrate	Silicate	Phosphate	Chl-*a*
3.75	17.58	35.39	4.70	0.49	3.04	0.26	1.19
10.50	17.50	35.38	4.88	0.51	2.88	0.26	1.75
21.33	17.28	35.39	4.62	0.68	3.09	0.53	1.09
30.60	17.01	35.39	4.62	1.32	3.04	0.29	1.19
50.11	16.19	35.50	4.50	3.09	4.00	0.54	-
100.67	13.51	35.17	4.06	8.79	6.10	0.82	-
200.00	11.06	34.91	4.08	13.01	7.11	1.09	-
296.67	9.69	34.73	3.84	18.85	8.95	1.35	-
399.33	6.74	34.47	4.63	20.60	16.67	1.63	-
493.80	5.98	34.41	4.06	23.23	20.84	1.81	-
557.86	5.80	34.38	3.88	24.65	22.15	1.85	-

Late summer (2004-2009)

Depth	Temperature	Salinity	Oxygen	Nitrate	Silicate	Phosphate	Chl-a
4.29	19.52	35.4	4.84	1.02	1.96	0.22	1.14
11.08	19.3	35.4	4.95	2.22	2.66	0.25	1.4
19.64	19.24	35.39	4.76	1.45	2.43	0.26	0.64
30.64	18.20	35.34	4.95	3.95	5.28	0.50	1.66
51.71	15.92	35.23	4.42	5.01	4.44	0.51	0.98
101.45	13.46	35.16	4.24	7.44	4.80	0.63	-
206.56	11.21	34.91	4.26	11.70	6.25	0.96	-
307.00	9.13	34.67	3.72	18.35	12.08	1.36	-
410.40	7.18	34.50	3.97	23.58	18.56	1.70	-
504.50	6.34	34.42	3.37	22.72	23.73	1.97	-
562.92	5.40	34.36	4.10	25.05	26.69	1.99	-

Winter (2004-2009)

Depth	Temperature	Salinity	Oxygen	Nitrate	Silicate	Phosphate	Chl-*a*
4.33	16.5	35.35	5.01	2.12	3.9	0.5	0.86
10.38	16.74	35.37	4.97	2	3.63	0.37	0.94
20.21	16.57	35.36	4.96	2.01	4.12	0.48	0.96
30.92	16.48	35.35	4.94	2.4	3.95	0.39	0.79
51.5	15.81	35.3	4.98	3.59	4.26	0.51	0.26
100.36	13.53	35.09	4.37	7.7	5.93	0.83	0.17
203.8	10.3	34.8	3.8	15.39	10.79	1.39	-
299.83	8.99	34.67	3.81	17.27	13.29	1.47	-
402.14	7.31	34.49	3.81	19.32	16.2	1.76	-
502.11	5.83	34.38	4.57	22.55	20.91	1.86	-
556.63	5.25	34.35	4.24	23.73	23.46	1.86	-

Appendix 2

Publications

Ismail, H.E., Agenbag, J.J., de Villiers, S. and Ximba, B.J., 2015. Relation between upwelling intensity and the variability of physical and chemical parameters in the southern Benguela upwelling system. *International Journal of Oceanography*, *2015*. 510713. doi: 10.1155/2015/510713.

Poster presentations

Ismail HE (2010). Determination of dissolved inorganic nutrients (NO_3^- and NO_2^-) in seawater by flow injection analysis using a photometric technique.*16th International Conference on Flow Injection Analysis, Pattaya, Thailand, 25-30 April 2010.*

Ismail HE, Ximba BJ, Tsanwani M and Illert C (2010). Determination of Dissolved Inorganic Nutrients (NO_3^- and NO_2^-) in seawater by flow injection analysis. *Research Day, CPUT, Cape Town, 3 December 2010.*

HE Ismail, BJ Ximba, M Tsanwani and C Illert (2010). Determination of Phosphate (PO_4^{3-}) in seawater by Flow Injection Analysis using a photometric technique. *Analitika 2010 Conference, Stellenbosch University, Cape Town, SA, 5-9th December 2010.*

Ismail HE, Ximba BJ, Tsanwani M & Illert C (2011). Determination of Dissolved Silicate in seawater by Flow Injection Analysis using a Photometric technique.*40th SACI Conference Wits University, Johannesburg, South Africa, 16-21st January 2011.*

HE Ismail and JJ Agenbag (2011). Investigating relationships between selected environmental parameters in St HelenaBay.*14th Southern African Marine Science Symposium, Rhodes University, Grahamstown, South Africa, 21-25th March 2011.*